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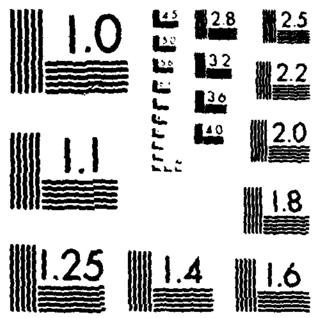

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A "Pawcatuck River and Narragansett Bay Drainage" (PNS) study.

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Flood forecasting
Water resources

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Presents the results of a study of water resource problems in the Woonasquatucket River Basin, Pawcatuck River Basin, and Narragansett Bay Local Drainage Areas.

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Pawcatuck River and Narragansett Bay
Drainage Basins

Pawcatuck and Woonasquatucket River Basins and Narragansett Bay Local Drainage Area

US Army Corps of Engineers
New England Division

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PAWCATUCK AND WOONASQUATUCKET RIVER BASINS AND NARRAGANSETT BAY LOCAL DRAINAGE AREA

APPENDIXES

NOVEMBER 1981

New England Division
U.S. Army Corps of Engineers
Waltham, Massachusetts 02254

APPENDIX 1
PROBLEM IDENTIFICATION

APPENDIX 1: PROBLEM IDENTIFICATION

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PURPOSE AND AUTHORITY

The purpose of this study was to investigate and determine the advisability of improvements for flood control and associated water resource problems in the Woonasquatucket River Basin, the Pawcatucket River Basin, and the Narragansett Bay Tidal Flood Area and to develop a viable plan consistent with these areas' economic, social and environmental well-being.

This report is submitted in partial compliance with seven Congressional resolutions, combined under one resolve by the Committee on Public Works of the United States Senate, adopted 29 March 1968:

> "That the Board of Engineers for Rivers and Harbors, created under Section 3 of the River and Harbor Act, approved 13 June 1902, be, and is hereby requested to review the report on Land and Water Resources of the New England-New York Region, transmitted to the President of the United States by the Secretary of the Army on 27 April 1956, and subsequently published as Senate Document Number 14, Eighty-fifth Congress, with a view to determining in light of the heavy damages suffered during the storm of March 1968, in southern New England, the advisability of improvements, particularly in the Pawcatuck River Basin, Rhode Island, and in the Narragansett Bay Drainage Basin, Massachusetts and Rhode Island, in the interest of flood control, navigation, water supply, water quality control, recreation, low-flow augmentation and other allied water uses."

Previous authority was given by a Senate Resolution adopted 8 May 1967 to review the Blackstone River, Massachusetts and Rhode Island in the interest of flood control and allied purposes. Subsequent to the major flood of March 1968, and the 29 March 1968 resolution, five other separate resolutions were adopted by the U.S. Senate and House of Representatives with particular reference to the Pawcatuck River and Narragansett Bay Drainage Basins and to sub-basins within the Narragansett Bay Drainage area. The seven outstanding resolutions have been combined in this study.

SCOPE OF THE STUDY

This report presents the results of a study of water resource problems in the Woonasquatucket River Basin, Pawcatuck River Basin and Narragansett Bay Local Drainage Area. These areas are included in 3 of the 5 portions of other major elements of the Pawcatuck River and Narragansett Bay Drainage Basins (PNB) Study. A map showing the relationship of these three segments to the entire PNB Study area is shown on Plate 1-1. All appropriate alternative plans to solve the areas' water resource problems were considered, and several protection schemes were studied in detail. Selection of the most feasible plan was made after considering all factors including those comments expressed by concerned Federal and State agencies and local interests. This study was made in the depth and detail necessary to permit plan selection and determine its economic, social and environmental feasibility.

The remainder of the river basins included in the authorizing resolution have been considered in separate feasibility studies.

STUDY PARTICIPANTS AND COORDINATION

The New England Division, U.S. Army Corps of Engineers, had the responsibility for conducting and coordinating the study, consolidating information from other studies, formulating plans, and preparing this report. During the course of the study, meetings were held with appropriate Federal and State government agencies and with local officials and interests of the towns and cities in which these basins lie, in order to coordinate study proposals with the plans and goals of these organizations and interests.

Four initial public meetings were held in May 1969 for the PNB Study. Those meetings were held in Providence and Kingston, Rhode Island and Taunton and Uxbridge, Massachusetts. The purpose of those meetings was to afford local interests an opportunity to express their needs and desires, to exchange information concerning the study, and to comment on some of the possible plans that could be considered.

PRIOR STUDIES AND REPORTS

EARLY RHODE ISLAND WATER SUPPLY REPORTS

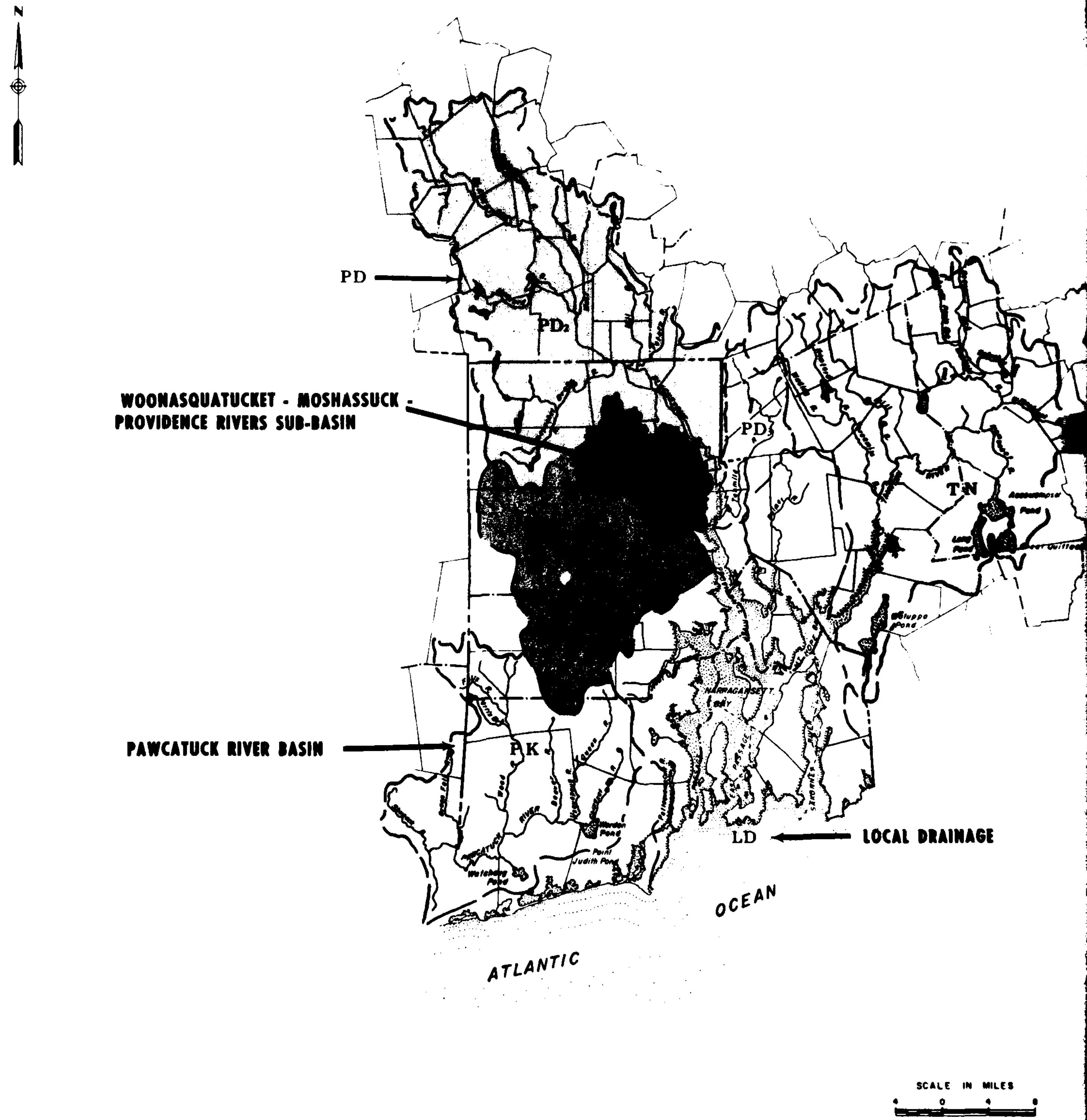
A report published in January 1928 by the Water Resources Board of Rhode Island investigated the sources of water supplies on the Woonasquatucket River. On September 29, 1936, *Special Report No. 9 of the* Rhode Island State Planning Board was published. This report provided information on the evaluation of the problems and needs of the basin together with the advocation of certain measures for minimizing flood damages.

FLOOD CONTROL SURVEY REPORT

Pursuant to Section 6 of the Flood Control Act of June 22, 1936, (Public Law No. 738-74th Congress) a report prepared in November 1937 by the Providence District, Corps of Engineers recommended that no further investigation for flood control be made of the Woonasquatucket River. Other than local interests exercising a greater degree of control in upstream storage reservoir and a maintenance program of existing improvements together with channel clearance along the Woonasquatucket River, the report recommended that flood prevention works were deemed unnecessary or unwarranted. Flood damages were so infrequent and of such minor importance at the time as to merit no further Federal expenditures.

NEW ENGLAND—NEW YORK INTER-AGENCY COMMITTEE REPORT

A report by the New England-New York Inter-Agency Committee (NENYIAC), referred to in the preceding authorizing resolutions was completed in March, 1955. It represented an inventory of resources



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PD2
WOONASQUATUCKET - MOSHASSUCK - PROVIDENCE RIVERS SUB-BASIN
PD3
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PAWCATUCK RIVER BASIN
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LOCAL DRAINAGE
NARRAGANSETT BAY
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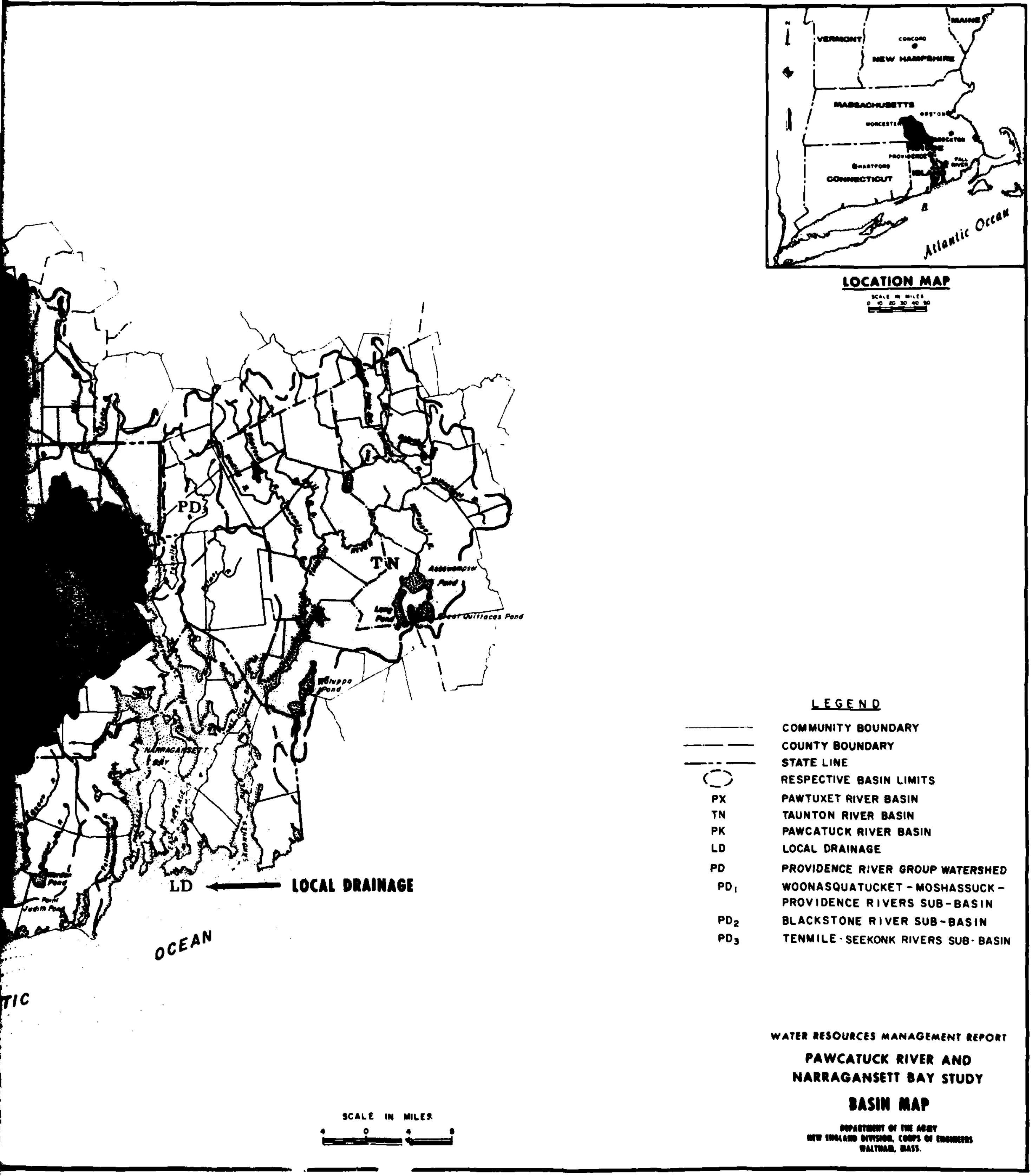
VERMONT
CONCORD
MAINE
NEW HAMPSHIRE
MASSACHUSETTS
BOSTON
WORCESTER
BROCKTON
PROVIDENCE
FALL RIVER
HARTFORD
CONNECTICUT
Atlantic Ocean
LOCATION MAP
SCALE IN MILES
0 10 20 30 40 50
PD3
TN
Assawompset Pond
Long Pond
Great Quittacas Pond
Watuppa Pond
NARRAGANSETT Bay
LD
LOCAL DRAINAGE
OCEAN
TIC
LEGEND
COMMUNITY BOUNDARY
COUNTY BOUNDARY
STATE LINE
RESPECTIVE BASIN LIMITS
PX PAWTUXET RIVER BASIN
TN TAUNTON RIVER BASIN
PK PAWCATUCK RIVER BASIN
LD LOCAL DRAINAGE
PD PROVIDENCE RIVER GROUP WATERSHED
PD1 WOONASQUATUCKET - MOSHASSUCK - PROVIDENCE RIVERS SUB-BASIN
PD2 BLACKSTONE RIVER SUB-BASIN
PD3 TENMILE - SEEKONK RIVERS SUB-BASIN
SCALE IN MILES
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WATER RESOURCES MANAGEMENT REPORT
PAWCATUCK RIVER AND
NARRAGANSETT BAY STUDY
BASIN MAP
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.

PLATE 1-1

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entailing streamflow regulations, water supply, water quality, flood control, hydroelectric power, navigation, shore erosion, fish and wildlife, recreation, historic sites, land management, mineral production, and insect control. The report indicated that benefits could possibly be realized from streamflow regulation, pollution control and flood control measures in the Woonasquatucket River watershed, but no projects were recommended for these or other study elements. Part One (brief summary) and Chapter I of Part Two (general discussion) of the report have been published as Senate Document No. 14, 85th Congress, 1st Session. Chapter XVII of Part Two, "Narragansett Bay Drainage Basins", discusses briefly some of the resources of the Woonasquatucket River watershed.

FOX POINT BARRIER REPORT

In response to Public Law 84-71 study authority, which was adopted following the occurrence of the damaging hurricanes of 31 August and 11 September 1954, an interim report on Narragansett Bay Area was completed in August 1957 by the New England Division, Corps of Engineers. That report led to the 1958 authorization and 1961-66 construction of the Fox Point Barrier, consisting of a concrete gravity dam with connecting dikes and extending across the Providence River. The project provides virtually complete protection against hurricane tidal flooding for the downtown area of Providence. More specific details of the barrier, are covered in a later section of this appendix.

NAVIGATION SURVEY REPORTS

Fall River Harbor. In response to a resolution by the House of Representatives, a report was prepared in September 1929 by the New England Division and was modified in 1946, 1954 and 1968. Work was completed by March 1959 for all authorizations prior to 1954. The 1968 modifications are in the planning stages but face delays due to failure in reaching a dredged material disposal solution for deepening Mount Hope Bay and Tiverton channels from 35 feet to 40 feet. Additionally, replacement or modification of Brightman Street Bridge within the Taunton River Basin is required by the project; the Commonwealth of Massachusetts is uncertain of its plans in those areas. Consequently, the dredging of Mount Hope Bay is postponed indefinitely.

Warwick Cove. Located 10 miles south of Providence, Rhode Island, in the city of Warwick, the project was authorized in 1965 under Section 107 of the 1960 River and Harbor Act. It provided for an entrance channel 6 feet deep and 150 feet wide, an inner channel 6 feet deep and 100 feet wide to the head of the cove and 4 anchorage areas of 6 feet, totalling 13 acres in area. The existing project was completed in August 1966.

Cliff Walk. Cliff Walk overlooks Rhode Island Sound near the southwest end of Aquidneck Island, about 3 miles east of Brenton Point, Newport, and 25 miles south of Providence. It is a popular scenic and historical walk bordering the edge of eroding bluffs and cliffs along the southeast shore of the city of Newport.

The Federal project, authorized in 1965 (H.D. 288, 89th Congress, 1st Session), provides for protective measures from the western end of Newport Beach westward to the eastern end of Bailey Beach, a distance of 18,000 feet. The measures include intermittent reaches of backfill, dumped riprap, stone slope revetment, repairs to existing seawalls, grading and surfacing Cliff Walk and providing drainage facilities.

The provision of protective measures along 9,200 feet of the waterfront, from the west end of Newport Beach to the west property line of the Marble House, was completed in September 1972. The remaining 8,800-foot portion of the project has been placed in an "inactive" status due to a lack of local funds.

Bristol Harbor. In response to the 1968 River and Harbor Act (H.D. 174, 90th Congress, 1st Session), plans for a breakwater 1,600 feet long were authorized. With a top elevation of 10 feet above mean low water, the breakwater begins at a point about 400 feet west of the Coast Guard Pier and extends generally in a northwesterly direction. Since its authorization, no work has been done on the project. Bristol Harbor is located on the east side of Narragansett Bay about 13 miles southeast of the city of Providence.

Providence River and Harbor. First adopted in August 1937 (H.D. 173, 75th Congress, 1st Session), modification of the project was authorized in 1965 (S.D. 93, 88th Congress, 2nd Session) to provide deepening the ship channel to 40 feet, easing channel bends, extending the channel 6.2 miles southward to the southeast side of Prudence Island and providing a 30-foot channel along the India Point waterfront, eastward from the head of the main ship channel. Construction of the project modification commenced in 1967 under a continuing contract for removal of ordinary material. This work was completed in 1971. A contract for removal of rock and unclassified material was awarded in June 1973, however, the initiation of the work was held up until March 1975 by a court injunction relative to environmental concerns. After resolution, however, work began in August 1975 and the project was completed in January 1976. Dredging of the India Point Channel has been placed in the inactive category because the commercial navigation facility has relocated and the waterfront area is proposed for development as a recreational park.

Providence River and Harbor is the principal commercial waterway in Rhode Island. A study is in progress to determine the need for Federal participation in the removal of sources of debris along the shores of Providence River and Harbor.

RHODE ISLAND WATER SUPPLY REPORTS

The water supply needs of the basin have been examined in a number of earlier studies. These include work by Rhode Island Statewide Planning, the Northeastern United States Water Supply Study (NEWS) and the Southeastern New England Water and Related Land Resource Study (SENE).

Each of these studies used as a basis a report completed for the Rhode Island Water Resources Board by the consulting engineers Metcalf and Eddy, Inc.

The initial Metcalf and Eddy work prepared in June, 1967 updated earlier consultant reports to the Rhode Island Water Resources Board to reflect the drought conditions of the early 1960's and the attendant water supply problems. This report proposed a phased development program to meet increased demands expected in 1990 and 2020 through construction of a reservoir on the Big River just upstream from the existing Flat River Reservoir in the adjoining Pawtuxet River Basin. This reservoir would produce an initial 29 mgd of water supply for the Providence metropolitan service area. Also proposed were flood skimming of the Flat River and transfer to Big River Reservoir plus development of facilities that would store and divert flood flows from the Pawcatuck River Basin and the Moosup River, a tributary of the Thames River, to augment the yields of Big River Reservoir. In conjunction with these studies, the Water Resources Board during 1965-66 acquired 8,270 acres for the Big River Reservoir project. The Big River Reservoir project is being studied by the New England Division in a separate feasibility report which will include a detailed EIS. Under this proposal the future water needs for seven of the ten communities within the Woonasquatucket River watershed currently serviced by the Providence Water Board system would be met by this envisioned plan.

WATER SUPPLY STUDY

A report (under the Urban Studies program) has been completed by Metcalf and Eddy, investigating the development of feasible structural and/or nonstructural water supply alternatives to meet both domestic and industrial manufacturing water demands through the year 2020 of the communities within the Pawcatuck and Narragansett Bay drainage basins. The water supply needs of each community were analyzed and alternatives developed to meet these needs. Solutions considered include: implementation of various nonstructural measures such as conservation education, water saving devices and pricing policies; advocation of local sources, i.e., groundwater to its maximum potential, local surface water where necessary and if that fails, importing water from neighboring areas; a no action plan; and various combinations of the three.

NEWS STUDY FEASIBILITY REPORT

Under the authority of the 1965 Flood Control Act, a regionwide assessment of water supply problems of the metropolitan areas between Maine and Virginia was made as part of the Northeastern United States Water Supply Study, under the direction of the North Atlantic Division, Corps of Engineers. A draft report was prepared by the New England Division in November 1969 concerning long range water supply needs in Rhode Island and most of Massachusetts. In that report there were no surface water projects contemplated for the Woonasquatucket watershed. It was envisioned that the watershed areas would continue to be serviced by

existing and future developments as those recommended in the 1967 Metcalf and Eddy report to the Rhode Island Water Resources Coordinating Board. Neither were there any groundwater projects proposed for the Woonasquatucket watershed area by the U.S. Geological Survey, who analyzed all existing groundwater reports as their contribution to the study.

In the Pawcatuck River basin one project was investigated to meet the water supply demands of the Providence area by diverting water from Wood River to the proposed Big River Reservoir. It was also determined that the groundwater in the upper Pawcatuck River Basin has the potential of supplying water to south central Rhode Island, Jamestown and Newport.

FLOOD CONTROL RECONNAISSANCE REPORT

In initial response to the PNB Study request, a reconnaissance report was completed in October 1972 by the New England Division, Corps of Engineers, which presented the findings on preliminary study of the flood problems in the Providence River Group which includes the Woonasquatucket River watersheds.

The report indicated that the population growth and urbanization in the Providence River Group watersheds, have magnified land development problems in the suburban areas. A large percentage of the expansion has been within the flood plains and, in certain regions, significant natural valley storage has been lost. Land changes have adversely affected the runoff characteristics of the watershed and the hydraulic efficiency of channels. To minimize future flood losses, a flood management program composed of nonstructural and structural measures should be instituted to temper or guide economic development.

The preliminary study indicated that, although many potential solutions emerged, few were expected to be economically feasible. As no single solution, structural or nonstructural, predominated in the preliminary research, it was anticipated that various types of flood management would need to be incorporated into the final plan for it to be effective. Measures recommended to be investigated in the detailed studies were: multipurpose reservoirs, local protection projects at critical damage centers, modification of existing impoundments, channel improvement, diversion of floodwaters, flood proofing, urban redevelopment, small watershed treatment and nonstructural regulatory measures.

NORTH ATLANTIC REGIONAL WATER RESOURCES STUDY

Authorized by the 1965 Flood Control Act, the North Atlantic Regional Water Resources (NAR) Study was one of 20 regional studies conducted throughout the United States under Level A guidelines established by the Water Resources Council. Published in June 1972 by the North Atlantic Division, Corps of Engineers, the report encompassed all river basins draining into the Atlantic Ocean from Maine to Virginia and all New York

and Vermont areas draining into the St. Lawrence River from St. Regis, New York, eastward. The objective was to establish a broad master plan or framework as a basis for regional water and related land resources management. Fifteen water resource needs in each of the 21 subregions of the NAR study area were projected through the year 2020 according to several alternative planning objectives; environmental quality, national efficiency (or income), regional development, or mixed objectives. A basic finding for the entire study area was that NAR water resources cannot support further continuation of previous customary practices of increased development and consumption. Research, study and management of water, land and environmental resources are needed to reduce the needs for excessive monetary and natural resource investments.

The report indicated that the PNB area will need help in eliminating its unemployment. Its water resource management program should be oriented toward increasing regional development, but with some environmental quality constraints. Key long-term (2020) needs for the PNB area were: water quality management and improvement to meet State standards, availability of power plant cooling water (mostly salt water sites), water supply withdrawal and importation measures (with future shift expected by many industries from self supplied to publicly supplied systems), flood damage reduction measures as land becomes scarce, commercial navigation improvements, shore erosion protection for selected sites, and increased opportunities for water-oriented recreation, fish and wildlife recreation, and recreational boating.

HYDROPOWER REPORT

An inventory of hydropower potential at existing dam sites in Rhode Island was completed in May 1979. Similar studies have also been completed for the other New England states. Nine hundred dam sites were identified throughout Rhode Island. Several dams located on the Woonasquatucket and Pawcatuck Rivers were determined to warrant further evaluation for hydropower potential based on preliminary engineering practicability and economic feasibility analysis.

SOUTHEASTERN NEW ENGLAND (SENE) REPORT

As part of the program established by the 1965 Water Resources Planning Act that multiple-purpose, coordinated plans be developed for each sub-region or major river basin in the nation, a comprehensive level B study of the coastal basins of eastern Massachusetts, Rhode Island and the southeastern corner of Connecticut was authorized by the Water Resources Council. Under the direction of the New England River Basins Commission, a Federal-State study team evaluated existing, 1990 and 2020 needs in the SENE area (including all of the PNB area), principally those concerning water supply, water quality, recreation, marine management, flooding and erosion, minerals extraction, and the siting of electrical power and petroleum facilities. The report to the Water Resources

Council, submitted in March 1976, indicated that continuing urban growth in the SENE area can be accommodated but should be guided to protect fragile resources and make development more efficient.

Highlighted recommendations for meeting 1990 needs in the Woonasquatucket-Moshassuck River Basin are shown on Table 1-1. This table and references are from the SENE Study Report No. 7.

The SENE Study recognized that specific project proposals were being evaluated by the PNB Study to resolve the major flood problems in the lower basin. Therefore, the SENE Study concentrated its recommendations on regulatory, soil conservation and forestry measures that all basin municipalities should adopt in the interest of reducing flood plain encroachment, erosion and non-point source pollution. It further coordinated its efforts closely with those of the PNB Study.

Highlighted recommendations for meeting the 1990 needs in the Local Drainage Area to Narragansett Bay are shown on Table 1-2. This table and references are from the SENE Study Report No. 9, Narragansett Bay and Block Island Planning Area Report.

Highlighted recommendations for meeting the 1990 needs in the Pawcatuck River Basin are shown on Table 1-3. This table and references are from the SENE Study Report No. 10, Pawcatuck Planning Area Report.

FLOOD INSURANCE STUDIES

Under the authority of the National Flood Insurance Act of 1968, Flood Insurance Study reports have been completed for the Federal Emergency Management Agency (FEMA) for most of the communities within the basin. Table 1-4 lists those towns and cities included and the status of each report.

STUDIES IN PROGRESS

In Fiscal Year 1974 the original Pawcatuck River and Narragansett Bay Drainage Basins Study (PNB) was reoriented to an Urban Study Program as a means of being more responsive to the water and related land resources problems and needs of this urban area. The program would have included urban problems and needs of this urban area. The program would have included urban flood control and flood plain management; municipal and industrial water supply; wastewater management; lake, ocean and estuarine restoration and protection; conservation of fish and wildlife resources; and regional labor and waterway development. Its first major effort would have been the development of wastewater management solutions to carry out the intent of the Federal Water Pollution Control Act Amendments of 1972, PL 92-500. Due to the initial lack of response from the States of Massachusetts and Rhode Island in indicating their intent towards the program and the cost sharing requirements of the wastewater management component, the Urban Studies Program was delayed until the Spring of 1975

TABLE 1-1

SENE Recommendations

Blackstone & Vicinity

GUIDING GROWTH (Chapter 3)

1. Protect priority Critical Environmental Areas.
2. Restrict development on other Critical Environmental Areas.
3. Manage growth on Developable Areas.
4. Incorporate SENE Study findings into the Rhode Island land use plan.
5. Use SENE resource development capability analysis to guide future growth in Massachusetts.
6. Accommodate growth where services already exist.

WATER SUPPLY (Chapter 4)

1. Survey ground water location, quantity, and availability in Upper Blackstone basin.
2. Meter all water use in the Upper Blackstone for planning system management.
3. Investigate advantages of closer water system cooperation in Upper Blackstone.
4. Increase activities in field of water supply, public information, and education in the Upper Blackstone.
5. Expand Worcester's existing surface water systems.
6. Establish connections to Worcester system in Auburn, Millbury, Grafton, Shrewsbury, and Upton.
7. Explore and develop ground water sources in the Upper Blackstone municipalities.
8. Pursue local surface water development only where necessary in the Upper Blackstone.
9. Develop interconnection with Uxbridge to serve Millville.
10. Investigate development of Hopedale Pond as a water supply source.
11. Acquire Tarkiln and Nipmuc Reservoir sites by 1990.
12. Plan for protection of reservoirs serving Pawtucket, Cumberland, and Woonsocket.
13. Construct iron and manganese removal facilities for Cumberland's sources.
14. Make plans to treat and use Harris Pond to augment Woonsocket's existing supplies.
15. Explore and develop additional ground water in North Smithfield.
16. Consolidate the existing water systems serving Burrillville.
17. Develop additional ground water to serve Chepachet section of Glocester.
18. Develop additional ground water in Plainville, Seekonk, and North Attleborough.
19. Supplement Attleboro supplies through the Taunton regional system.
20. Establish an emergency connection between North Attleborough and Taunton.
21. Consolidate three systems currently serving Smithfield.
22. Petition the General Assembly to approve construction of the Big River Reservoir.
23. Expand and treat ground water supplies in Lincoln.

WATER QUALITY (Chapter 5)

1. Carry out current state non-degradation policies.
2. Emphasize treatment of combined sewer overflows.
3. Begin stormwater and wet-weather stream sampling.
4. Continue current industrial permits program.
5. Construct advanced treatment plant for Upper Blackstone towns.
6. Complete separation of combined sewers in Worcester by 1980.
7. Upgrade treatment plant to advanced to serve Millbury and Sutton.
8. Construct advanced treatment plant in Grafton.
9. Maintain advanced treatment plant in Northbridge.
10. Provide advanced treatment in Upton after 1985.
11. Provide advanced treatment in Hopedale by 1978.
12. Construct advanced treatment plant in Uxbridge by 1978.
13. Construct secondary treatment plant in Douglas.
14. Connect Blackstone to Woonsocket's treatment plant by 1976.
15. Provide secondary treatment in Woonsocket and other towns by mid-1977.
16. Construct secondary treatment plant in Burrillville by mid-1977.
17. Maintain secondary treatment plant for Blackstone Valley Sewer District.
18. Provide partial separation of combined sewer overflows in Central Falls and Pawtucket.
19. Expand and upgrade North Attleborough plant to advanced by 1977.
20. Expand and upgrade Attleboro plant to advanced by 1979.
21. Provide secondary treatment to Barrington from East Providence plant.
22. Construct advanced treatment plant in Smithfield.
23. Expand sewer service in Lincoln.
24. Continue service from Providence treatment facility to five municipalities.
25. Study and define the landfill leachate problem.

OUTDOOR RECREATION (Chapter 6)

General Outdoor Recreation

1. Develop guidelines to plan for low-intensity recreation on storage reservoir lands.
2. Acquire local access near 4 Rhode Island lakes.
3. Acquire statewide access along Crystal Pond in Douglas.
4. Acquire inner-city recreation opportunities in at least 6 municipalities.
5. Consider a trail system from Douglas to Providence.
6. Enlarge Douglas State Forest, consolidate Upton State Forest, and provide support for the towns.
7. Expand Diamond Hill, Lincoln Woods, and Casimir Pulaski State Parks.
8. Create a Ten Mile River recreation complex.
9. Create a Blackstone River Park.
10. Use SENE Development Capabilities Maps for open space protection.

Fish and Wildlife

11. Use the Massachusetts Natural Resources Planning Program to enforce wetlands legislation.
12. Provide technical assistance to Rhode Island municipalities to enforce wetlands legislation.
13. Acquire the most significant wildlife habitats.
14. Include ponds 10 acres and larger for fishing in Massachusetts Great Ponds legislation.
15. Acquire access to ponds with good potential for fisheries production.
16. Acquire access to streams with good potential for fisheries production.

MARINE MANAGEMENT (Chapter 7)

1. Coordinate local waterfront planning and development.
2. Provide guidance and set criteria at the state level for priority waterfront uses.
3. Review and coordinate waterfront use.
4. Provide federal funding support for state and local waterfront development plans.

(See also Narragansett Bay Planning Area Report.)

FLOODING AND EROSION (Chapter 8)

1. Develop comprehensive flood plain management programs giving priority to non-structural measures.
2. Apply structural solutions selectively.
3. Adopt local flood plain zoning preventing adverse flood plain development.
4. Establish local sediment and erosion control ordinances.
5. Establish forest buffer zones.
6. Establish a forestry program.
7. Establish local regulations to strengthen flood plain management.
8. Acquire key flood plains and wetlands.
9. Locate in existing safe buildings in the flood plain.

LOCATING KEY FACILITIES (Chapter 9)

See Regional Report – Chapter 9

TABLE 1-2

SENE Recommendations

Narragansett Bay

GUIDING GROWTH (Chapter 3)

1. Protect priority Critical Environmental Areas.
2. Restrict development on other Critical Environmental Areas.
3. Manage growth on Developable Areas.
4. Use SENE resource development capability analysis to guide future growth.
5. Accommodate growth where services already exist.

WATER SUPPLY (Chapter 4)

1. Extend Providence Water Supply Board service to Warwick.
2. Continue ground water exploration in East Greenwich.
3. Extend Providence Water Supply Board service to Barrington, Bristol, and Warren.
4. Begin an intensive watershed control program for the Jamestown system.
5. Maintain existing resources, with long-term reliance on the Big River Reservoir, in four lower Narragansett Bay communities.
6. Ensure efficient reallocation of U. S. Navy base water supplies in Newport.
7. Rely on local ground water in Narragansett, New Shoreham, North Kingstown, and Rehoboth.
8. Construct two offstream reservoirs in Swansea.
9. Consolidate North Tiverton and Stone Bridge Fire Districts.
10. Set streamflow depletion standards near North Kingstown's wells.

WATER QUALITY (Chapter 5)

1. Construct a secondary wastewater treatment facility in New Shoreham.
2. Construct a secondary wastewater treatment facility in Narragansett.
3. Serve Barrington by the East Providence treatment facility.
4. Upgrade the Newport treatment facility to secondary.
5. Continue partial separation of combined sewers in conjunction with treatment techniques.
6. Continue to serve Warwick by a secondary treatment facility.
7. Construct a secondary treatment facility in Jamestown.
8. Serve northern Tiverton by the Fall River treatment facility.
9. Serve Swansea by the Somerset facility.
10. Expand Quonset Point plant to serve North Kingstown and a portion of Warwick.
11. Upgrade Bristol plant to secondary treatment and serve Warren.
12. Abandon Scarborough Hills facility and connect to Narragansett regional facility.

OUTDOOR RECREATION (Chapter 6)

Swimming

1. Continue weekend bus service from Providence to beaches.
2. Acquire a new public beach in Warwick.
3. Acquire nearly a mile of public beach in North Kingstown.
4. Acquire local beaches in Portsmouth, Jamestown, and North Kingstown.
5. Secure public access to the shoreline.

Recreational Boating

6. Construct authorized project at Bristol Harbor.
7. Maintain 14 existing navigation channels.
8. Develop 2 new navigation channels and a boat landing.
9. Guide future development of marinas in 22 localities.
10. Investigate new regional harbors in Narragansett Bay.

General Outdoor Recreation

11. Develop Narragansett Bay Islands Park.
12. Develop Block Island for recreation.
13. Develop area around Hundred Acre Cove and Runnin's River.
14. Develop urban parks along Warwick's coast.
15. Protect Pettaquamscutt River Corridor for low-intensity recreation and conservation.
16. Acquire access to Secret Lake and Kettle Hold Pond.
17. Use SENE Development Capabilities Maps for open space protection.

Fish and Wildlife

18. Provide assistance to municipalities for enforcing wetlands legislation.
19. Acquire public access to ponds with high potential for fisheries production.
20. Acquire significant wildlife wetlands.
21. Acquire public access to 5 streams.
22. Improve anadromous fish stocks.

MARINE MANAGEMENT (Chapter 7)

Port Development

1. Complete Fall River channel as soon as suitable disposal sites are approved.
2. Complete Providence Channel.
3. Develop channel improvements for Newport and Port Judith fishing industry.
4. Develop rigid operational guidelines for LNG and oil development.

Shellfish

5. Consider recreational shellfish licensing.
6. Eliminate combined sewer overflows in Providence.

Offshore Fisheries

7. Continue to support an interim offshore 200-mile economic zone.
8. Support national fisheries management policy.
9. Improve market for underutilized fish species.
10. Accommodate coastal fish facilities through improved planning.
11. Allow privately financed purchase of foreign-built fishing vessels.

Urban Waterfronts

12. Coordinate local waterfront planning and development.
13. Provide public waterfront vantage points.
14. Provide guidance and set criteria at the state level for priority waterfront uses.
15. Review and coordinate waterfront use.
16. Provide federal funding for state and local waterfront development plans.

FLOODING AND EROSION (Chapter 8)

1. Develop flood plain management programs which maximize non-structural solutions.
2. Adopt local flood plain zoning preventing adverse flood plain development.
3. Establish local sediment and erosion control ordinances.
4. Establish forest buffer zones.
5. Establish local regulations to strengthen flood plain management.
6. Acquire significant flood plains and wetlands.
7. Locate in existing safe buildings in the flood plain.
8. Encourage natural stabilization of coastal erosion areas.

LOCATING KEY FACILITIES (Chapter 9)

See Regional Report, Chapter 9

TABLE 1-3

SENE Recommendations

Pawcatuck River

GUIDING GROWTH (Chapter 3)

1. Protect priority Critical Environmental Areas.
2. Restrict development on other Critical Environmental Areas.
3. Manage growth on Developable Areas.
4. Use SENE resource development capability analysis to guide future growth.
5. Accommodate growth where services already exist.

WATER SUPPLY (Chapter 4)

1. Maintain all existing water supplies and protect recharge areas.
2. Consolidate existing water supply systems in planning area municipalities.
3. Acquire additional well sites in planning area municipalities.
4. Obtain additional water supply for Stonington from the Mystic Valley Water Company.
5. Carry out data acquisition on aquifers in Pawcatuck planning area.

WATER QUALITY (Chapter 5)

1. Accelerate municipal wastewater treatment plant construction.
2. Continue the current industrial permits program.
3. Carry out current state non-degradation policies.
4. Provide streambank buffer strips.
5. Provide pump-out facilities and treatment for watercraft wastes.
6. Study and define the landfill leachate problem.

OUTDOOR RECREATION (Chapter 6)

Swimming

1. Continue local management of Quonochontaug Beach and acquire Green Hill Beach.
2. Waive liability for landowners who permit public access for recreation.
3. Secure public access to the coastline.

Boating

4. Continue maintenance of existing channels.
5. Guide development of existing marinas.
6. Provide public boat ramps and fishing piers.

General Outdoor Recreation

7. Develop scenic rivers legislation to protect stretches of the Pawcatuck, Wood, and Beaver Rivers.
8. Increase facilities in four state parks.
9. Acquire ponds along the Connecticut-Rhode Island border.
10. Use SENE Development Capabilities Maps for open space protection.

Wildlife and Fresh Water Fisheries

11. Improve enforcement of wetlands legislation.
12. Acquire most important wildlife habitats.
13. Acquire fishing access to potentially productive ponds.
14. Acquire fishing access to potentially productive streams.

MARINE MANAGEMENT (Chapter 7)

Aquaculture and Shellfish

1. Investigate the potential of tidal ponds for aquaculture.
2. Consider recreational shellfish licensing.
3. Accelerate research on using atomic power plant wastewater for aquaculture.

FLOODING AND EROSION (Chapter 8)

1. Develop flood plain management programs which maximize non-structural solutions.
2. Adopt local flood plain zoning preventing adverse flood plain development.
3. Establish local sediment and erosion control ordinances.
4. Establish forest buffer zones.
5. Establish local forestry programs.
6. Establish local regulations to strengthen flood plain management.
7. Acquire significant flood plains and wetlands.
8. Locate in existing safe buildings in the flood plain.
9. Encourage natural stabilization of coastal erosion areas.

LOCATING KEY FACILITIES (Chapter 9)

1. Continue planning the Charlestown nuclear power complex, applying environmental and safety criteria.

TABLE 1-4

STATUS OF FLOOD INSURANCE STUDIES

Woonasquatucket-Moshassuck	Type 15*	Type 19
Johnston, R.I.	1978	
North Providence	1977	
Smithfield	1976	
Providence	1970	started 1978
Pawcatuck		
Charlestown, R.I.	1972	
Exeter	started 1978	
Hopkinton	started 1976	
Richmond	started 1976	
South Kingstown	1972	
West Greenwich	1973	started 1978
Westerly	1972	
Local Drainage		
Barrington	1971	started 1978
Bristol	1972	
Cranston	1971	
East Greenwich	1973	
East Providence	1973	
Jamestown	1972	
Little Compton	started 1978	
Middletown	1971	started 1978
Narragansett	1971	started 1978
Newport	1970	started 1978
North Kingstown	1972	started 1978
Pawtucket	1971	started 1978
Portsmouth	1973	started 1978
Providence	1970	started 1978
South Kingstown	1972	
Tiverton	1976	started 1978
Warren	1972	started 1978
Warwick	1973	1976
Westerly	1972	

*Type 15 - Regular Study
Type 19 - Restudy

at which time both States elected to accomplish the wastewater management component under the provision of Section 208 of PL 92-500. Subsequently a revised Plan of Study for the Urban Study Program was developed and approved by the concerned agencies. The revised program called for the Corps to perform water supply studies, an expanded flood plain management study for the Moshassuck River Basin, a navigation reconnaissance report for the Narragansett Bay area, as well as construction of the ongoing flood control studies.

BASIN DESCRIPTIONS

PAWCATUCK RIVER BASIN

The Pawcatuck River basin lies in the southwestern corner of Rhode Island except for three small portions located within southeastern Connecticut; where the Pawcatuck River forms the boundary between the two states at its outlet into Block Island Sound, the western portion which is drained by the Shunock River, and a still smaller portion of eastern Connecticut drained by the Green Fall River, a headwater tributary. The total drainage area as shown in Plate 1-2 is 303 square miles of which 246 square miles are in Rhode Island and the remaining 57 in Connecticut.

The basin is bounded by the Eastern Connecticut Coastal Area and the Thames River basin on the west, the Narragansett Bay drainage basin on the north and east, and the Rhode Island coastal area on the south. The basin drains the southern portion of Kent County and the major portion of Washington County in Rhode Island as well as the southeastern corner of New London County in Connecticut.

The Pawcatuck River rises in Worden Pond, which is situated in Great Swamp, South Kingstown in the southeastern portion of the basin. It flows a distance of 33 miles through a multitude of lakes and swamps, with only one major urbanized area along its river banks: the Rhode Island town of Westerly on the left bank and the adjacent Connecticut section of Stonington called Pawcatuck on the right bank. These areas, located approximately five miles upstream from the river's mouth at Little Narragansett Bay are at the upstream limits of the normal tidal influence. The principal tributaries of the Pawcatuck River are the Usquebaug, Beaver, Wood, Ashaway and Shunock Rivers. They drain a total of 210 square miles, about 70 percent of the entire Pawcatuck River drainage area of 303 square miles. The remaining 93 square miles is the local drainage into the Pawcatuck River itself through very small tributaries.

The Usquepaug River, with a drainage area of 44 square miles, accounts for about 15 percent of the Pawcatuck's drainage area. It rises in Glen Rock Reservoir in northwest South Kingstown, Rhode Island, and flows in a generally southern direction about 4.5 miles to its confluence with the Pawcatuck River in Great Swamp, about 1.5 miles below the outlet of Worden Pond. The total fall in the Usquepaug River is about 25 feet. The principal headwater tributary is the Queen River.

The Beaver River with a drainage area of 12 square miles, accounts for about 4 percent of the basin's total drainage area. It commences flow at the outlet of James Pond in central Exeter and flows in a southerly direction through Richmond for a distance of 10.2 miles before entering the Pawcatuck. Most of its drainage area is sparsely developed. The total fall in the Beaver is 305 feet.

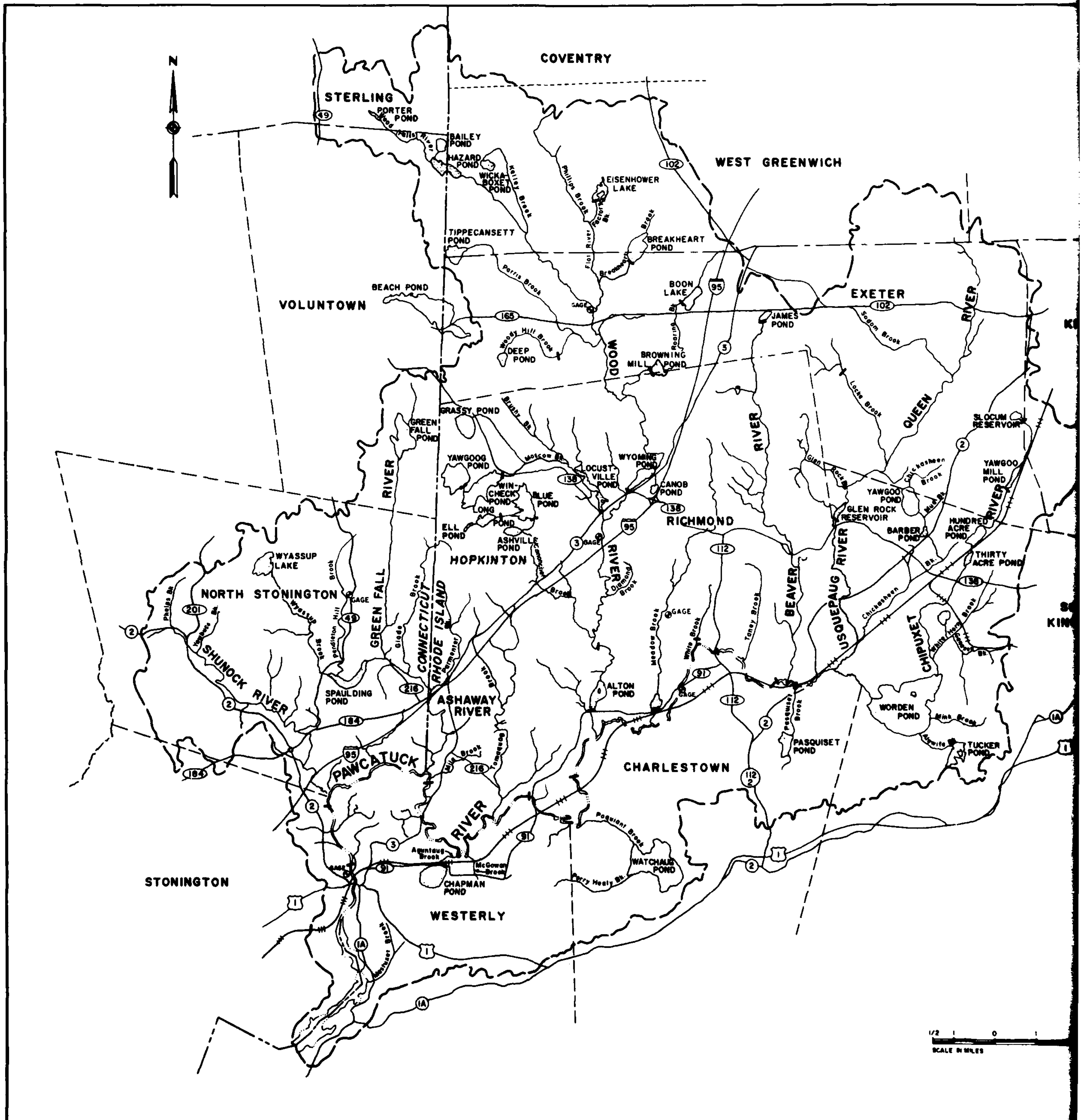
The Wood River, the southwestern part of West Greenwich, flows a total distance of 19 miles through Arcadia Reservation and then through the more heavily populated area of Hope Valley in Hopkinton, Rhode Island. Beyond Hope Valley, it continues south through the very sparsely settled countryside until it joins the Pawcatuck, thereby forming the boundaries among the Rhode Island towns of Hopkinton, Richmond and Charlestown about 22 miles upstream from the mouth of the Pawcatuck. It has a total drainage area of 87 square miles and the elevation drop in the major tributary is about 110 feet.

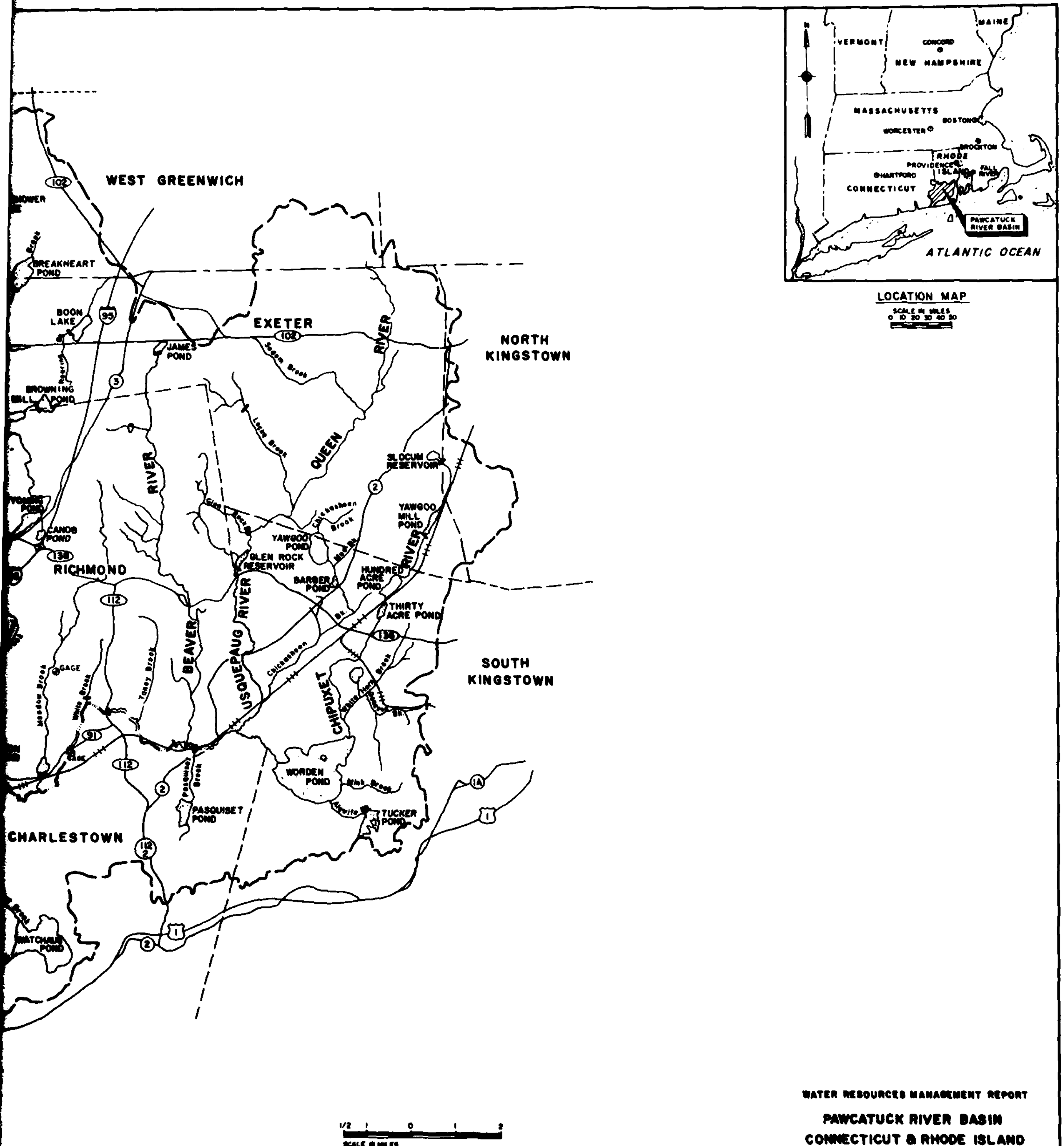
Further downstream along the Pawcatuck is the Ashaway River. It is formed by the Green Fall River and Parmenter Brook in the western part of Hopkinton, and flows southerly a distance of three miles through the village of Ashaway to its confluence with the Pawcatuck River at the intersection of the town lines of Hopkinton and Westerly, Rhode Island and North Stonington Connecticut, about 10 miles above the mouth of the Pawcatuck. The river itself only has an elevation drop of 20 feet, but drains a total area of 50 square miles, 17 percent of the entire Pawcatuck River Basin.

The Shunock River, with a drainage area of 17 square miles, accounts for about 6 percent of the basin drainage area. It is formed at the outlet of Hewitt Pond in the west central portion of the town of North Stonington, Connecticut. The river meanders in a generally southeast direction passing through the village of North Stonington, 38 miles from its headwaters. It then continues in the same direction travelling through sparsely settled countryside until it joins the Pawcatuck at the Connecticut-Rhode Island state line, about 7.7 miles above the mouth of the Pawcatuck. The total length of the Shunock is 8.2 miles, and it has a total fall of about 225 feet.

There are 9 dams located on the Pawcatuck River, all of which are shown on the River Profile on Plate 1-3. Plate 1-4 shows there are another 3 dams on the Wood River, a tributary of the Pawcatuck.

The Stillmanville Dam, located at river mile 5.6 of the Pawcatuck River in the Pawcatuck, Connecticut--Westerly, Rhode Island urbanized area, is in considerable disrepair. Initially, the dam was owned and operated by the Fiske Rubber Company. At this time, the dam has no use other than to maintain a small pond about the size of the width of the river (140' to 200') and 0.8 miles in length. The head developed by the


N
COVENTRY
STERLING
PORTER POND
BAILEY POND
HAZARD POND
WICKABOXET POND
Kelley Brook
EISENHOWER LAKE
WEST GREENWICH
Phillips Brook
TIPPECANSETT POND
BREAKHEART POND
Parris Brook
BEACH POND
VOLUNTOWN
BOON LAKE
EXETER
JAMES POND
Sodom Brook
DEEP POND
WOOD
BROWNING MILL POND
GRASSY POND
GREEN FALL POND
RIVER
YAWGOOG POND
WYOMING POND
LOCUSTVILLE POND
WINCHECK POND
BLUE POND
LONG POND
CANOB POND
RICHMOND
ELL POND
ASHVILLE POND
HOPKINTON
WYASSUP LAKE
NORTH STONINGTON
GREEN FALL
CONNECTICUT
RHODE ISLAND
QUEEN
SLOCUM RESERVOIR
YAWGOO MILL POND
GLEN ROCK RESERVOIR
BARBER POND
HUNDRED ACRE POND
THIRTY ACRE POND
BEAVER
USQUEPAUG
CHIPUXET
SHUNOCK RIVER
SPAULDING POND
ASHAWAY RIVER
ALTON POND
WORDEN POND
PASQUISET POND
TUCKER POND
PAWCATUCK
CHARLESTOWN
WATCHAUG POND
CHAPMAN POND
STONINGTON
WESTERLY
SCALE IN MILES



WATER RESOURCES MANAGEMENT REPORT

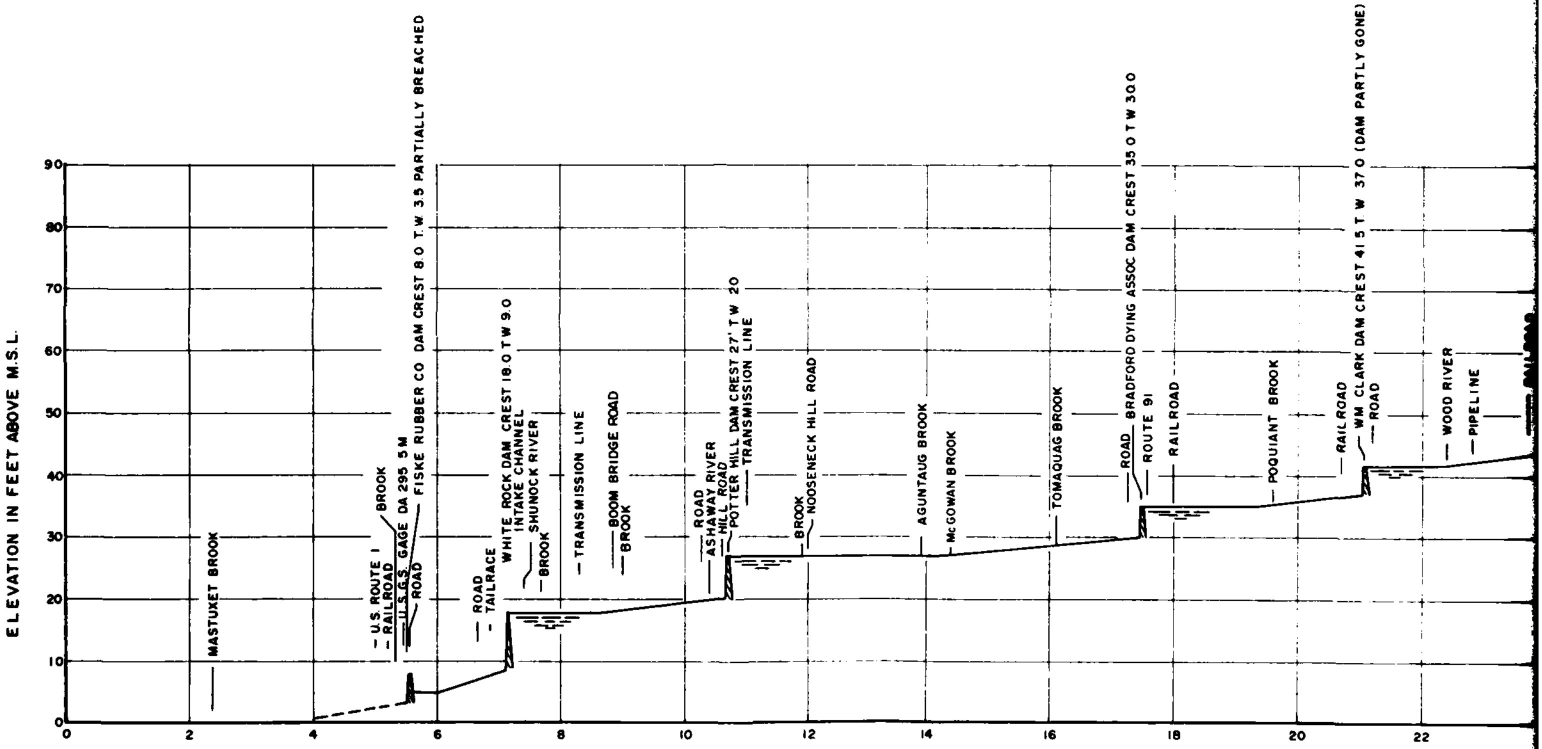
PAWCATUCK RIVER BASIN
CONNECTICUT & RHODE ISLAND

BASIN MAP

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.

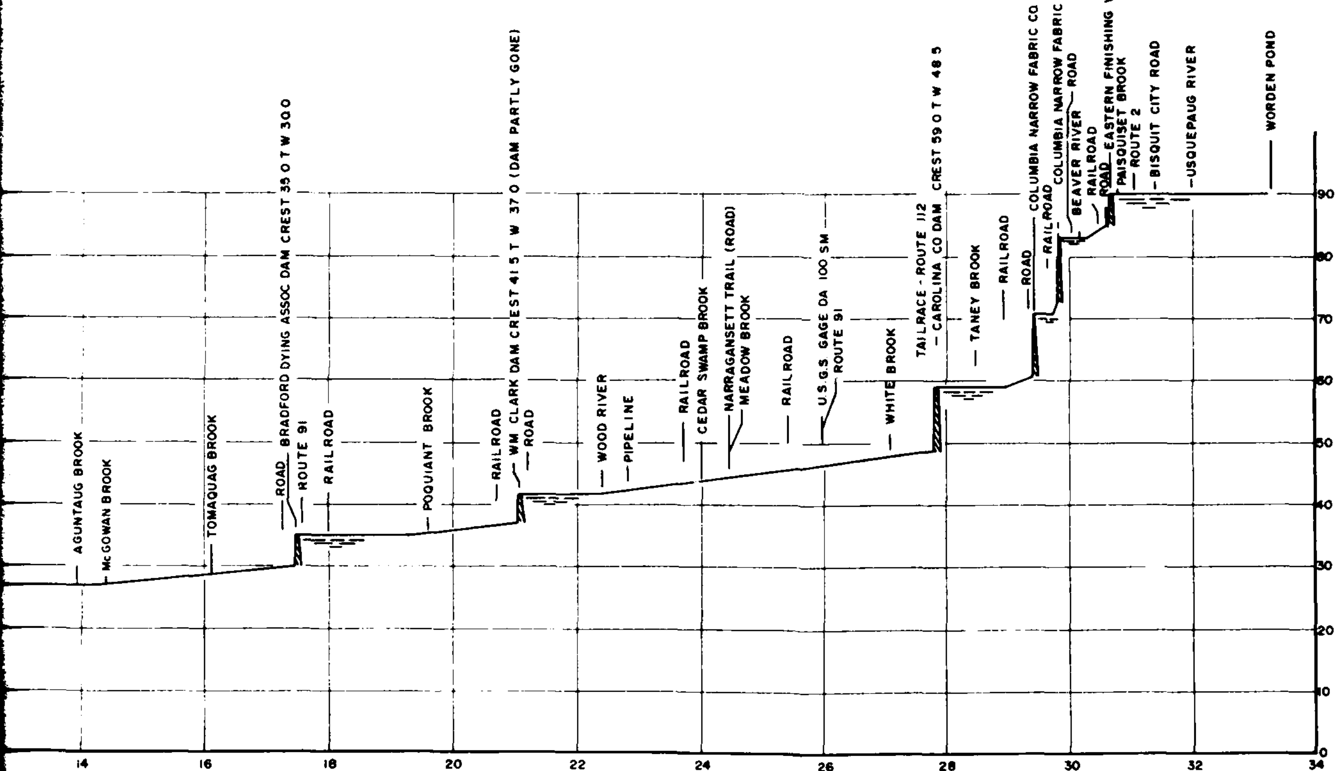
PLATE 1-2

2



PAWCATUCK RIVER ℄ PROFILE

RIVER MILES FROM MOUTH



PAWCATUCK RIVER ℄ PROFILE

RIVER MILES FROM MOUTH

WATER RESOURCES MANAGEMENT REPORT

PAWCATUCK RIVER BASIN

CONNECTICUT & RHODE ISLAND

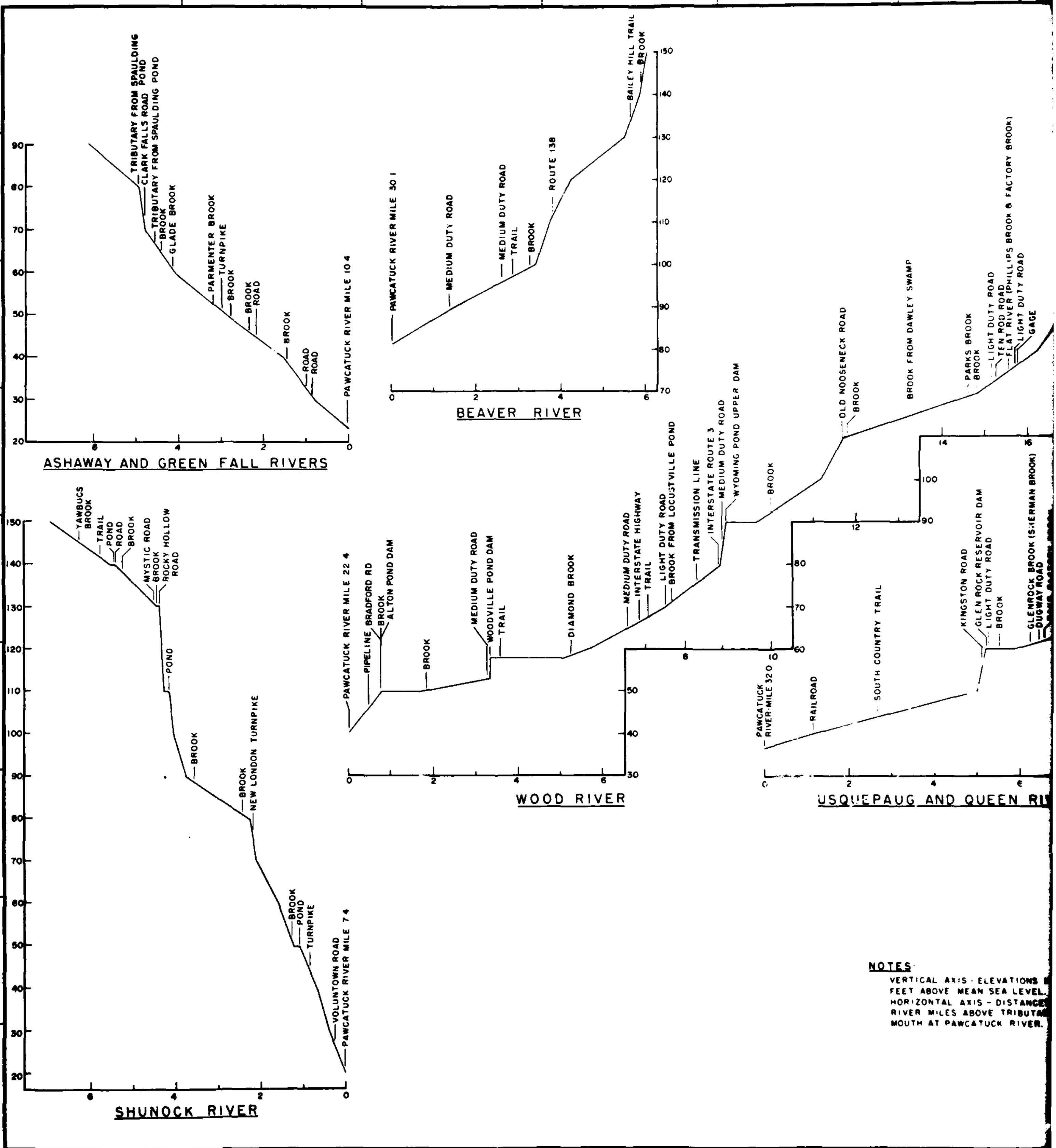
PROFILE PAWCATUCK RIVER

NEW ENGLAND DIVISION, CORPS OF ENGINEERS

PLATE 1-3

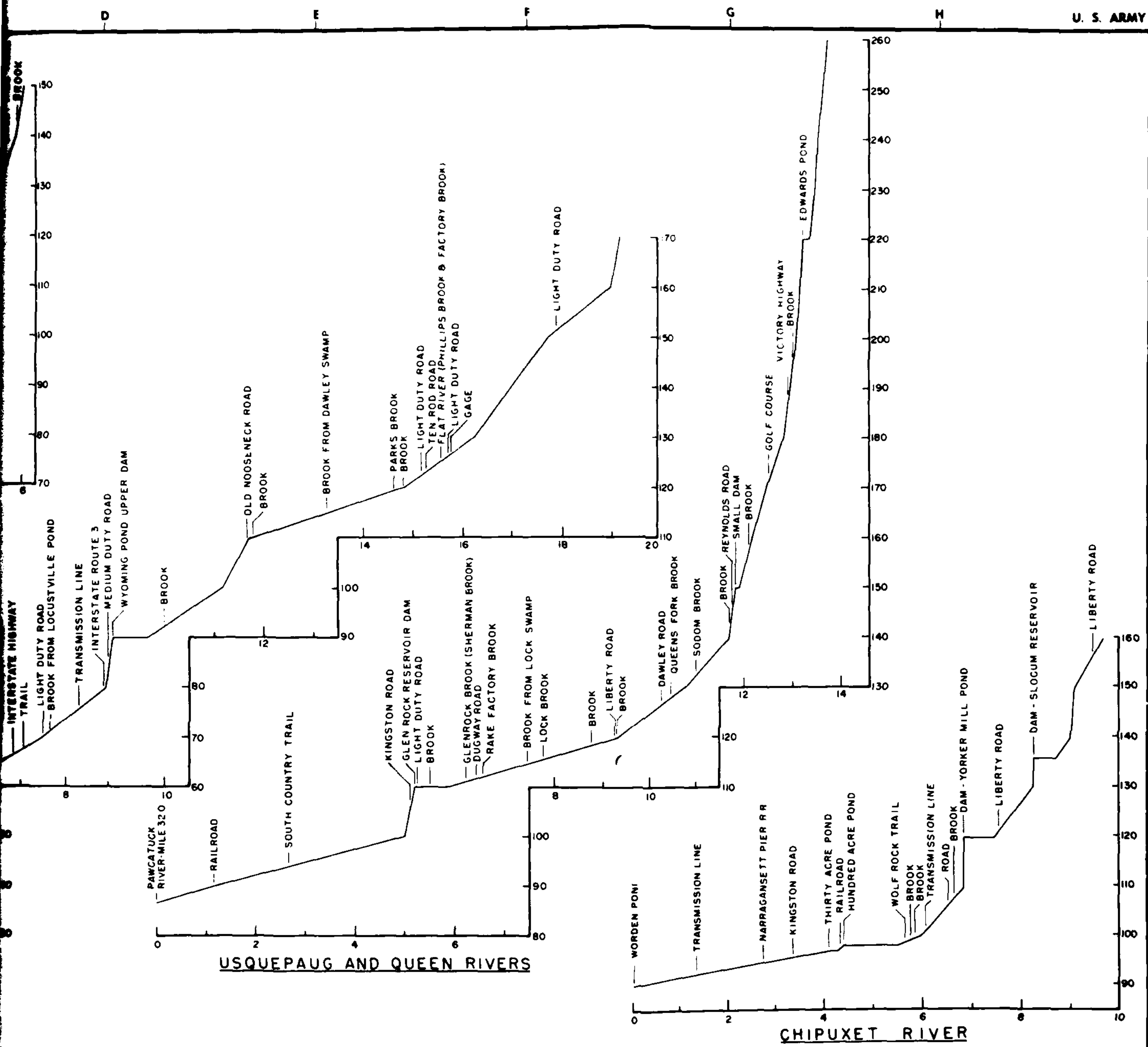
2

CORPS OF ENGINEERS



NOTES:
VERTICAL AXIS - ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL.
HORIZONTAL AXIS - DISTANCE IN RIVER MILES ABOVE TRIBUTARY MOUTH AT PAWCATUCK RIVER.

U. S. ARMY



NOTES:

VERTICAL AXIS - ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL
HORIZONTAL AXIS - DISTANCES IN RIVER MILES ABOVE TRIBUTARY MOUTH AT PAWCATUCK RIVER

REVISION	DATE	DESCRIPTION	BY

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

WATER RESOURCES MANAGEMENT REPORT

PAWCATUCK RIVER BASIN

TRIBUTARY PROFILES

PAWCATUCK RIVER — CONN. & R.I.

DATE JAN. 1977

PLATE 1-4

dam of 4.5′ when new (before siltation) impounded a pool of about 400 ac-ft, however, this reservoir is now largely filled with silt. The amount of present storage would not cause a serious problem downstream should the structure completely fail.

The Pawcatuck River is about 130′ wide at the Stillmanville Dam. The overflow section is 91′ long extending from the right bank perpendicularly across the stream to what was once an additional 36′ long overflow section. The overflow section, at a slightly higher elevation, fed a canal on the Rhode Island side or left bank. The canal was separated from the main river section by a stone wall about 4 feet wide and running for several hundred feet along the riverbank. This 36′ overflow section is just about completely destroyed and is handling much of the total river flow. As a result of the higher flows using the old canal, erosion control may have prompted the dumping of rock which protects the canal′s left bank. The wall separating the river from the canal is breached and the main 91′ overflow section is also damaged near its midsection. The weir, a concrete shell over rubble, was originally protected by wood planking on the downstream face. This planking is entirely gone and the dam is being undercut on the downstream side.

It appears that in time of extreme high flows, the river would overflow its banks inundating surrounding lands and buildings with or without the dam. Should the remaining structure be completely removed, the channel would become more efficient, lessening the chance of overbank flooding at this point. Active mill buildings, of two or more stories high, line both banks downstream of the dam.

The White Rock Dam, originally built about 1849, was rebuilt in 1931 and feeds an industrial canal, 0.8 mile in length, over 50′ wide and line with cut-stone walls. The canal was last reported as being in excellent shape. A timbered framed gate structure in the canal, 0.1 mile from the dam, is in ruins. The White Rock Dam itself at river mile 7.2 is a 112′ long concrete gravity overflow structure and is in good condition.

The pool impounded by the White Rock Dam with about 120 ac-ft of storage is particularly attractive. With general improvements in water quality this pond should increasingly be an asset to the adjacent communities of Stonington and North Stonington, Connecticut and Westerly, Rhode Island.

When the river water was used by the White Rock Finishing Company for power and processing, and the canal gate works were operable, the dam′s crest was topped by 2.3 feet of flashboards. These flashboards are now gone. The overflow dam now has an effective height of 6.2 feet, tailwater to crest.

Potter Hill Dam, approximately 10 feet high and in very good condition is located a few hundred feet upstream at the confluence with the Ashaway River. The State of Rhode Island recently constructed an

alewife fish ladder alongside the dam. The mill at this location is abandoned but in fair condition. The dam is a concrete ogee overflow section.

The Bradford Dam is situated adjacent to the Bradford Dye Works, a very active and modernized mill.

At Burdrickville, all that remains of the dam is rubble in the river. The site is located in a residential area.

The Carolina Company dam consisted of three sections of approximately 70, 90 and 110 feet. Apparently the gate in the 70' section was removed some time ago and the water level in the holding area behind the dam is extremely low. The 90 and 110-foot sections are completely dry while a 15-foot opening in the third section allows the pond to drain. Construction is concrete rubble for all three sections. The mill complex is abandoned; some buildings have burned down.

The Shannock Dam is a horseshoe dam with an effective length of approximately 80 feet. It is about 10 feet high and constructed of concrete rubble. The dam is in good condition. The intake channel to the abandoned mill at Shannock is operational. Approximately 2,000 feet downstream another similar dam in three straight sections with an effective length of 70' and a height of 5' is in fair condition. Construction is also concrete rubble.

At the Kenyon Piece Dyeworks a 75-foot long concrete rubble dam with a 5-foot head is in good condition. There is also an intake channel to the mill in use. There are two dams in Hope Valley, Rhode Island, one on the Wood River below the village and one on Locustville Pond at the village. The former is an arch dam approximately 15 to 20 feet high and 100 feet long adjacent to the remains of a destroyed mill complex. There appears to be little, if any, flood problems at or near this dam or in the downstream buildings. At the village the dam is in three sections with the largest approximately 50 feet long and 10 feet high. Construction is rubble in good condition. The problem at this location may be the highway bridge that carries Route 3 over Moscow Brook. The bridge opening is approximately 5' x 30' and does not seem sufficient to pass heavy flows. Since portions of the village are fairly low, any backup may inundate the businesses and fire station adjacent to the bridge. It should be noted that a chemical company (Aurolux Chemical Assn., Inc.) occupying the remaining mill building adjacent to the dam does use river water for cooling and has some capability to regulate the pond level. They have occupied the building since the summer of 1968 (after the spring flood).

At the Thames River Tube Co. at Bethel, upstream of the main village there is a small dam. Flooding in this area, even from a major event, would not cause any damages. At the Ashaway Road Bridge over the Ashaway River the bridge abutments serve as part of the Stepper Dam located under the bridge. Both are in excellent condition and in continual use.

The Pawcatuck River watershed has experienced several relatively infrequent floods yet the damages associated with them have been minimal. In order to establish and maintain a history of the flows in the basin, the U.S. Geological Society operates 5 gaging stations on various streams in the watershed. Table 1-5 gives the monthly discharge from October 1977 to September 1978 at the gage located in Westerly, Centerdale and Providence, Rhode Island.

In November 1929 the discharge was estimated between 3,800 cfs and more than twice the discharge of March 1936, computed as 3,150 cfs from flow over a dam 1-1/2 miles upstream from the gage. Discharges of 3,800 cfs were estimated for the storms of February 1886 and September 1932. Other high discharges for this period were September 1954 (Hurricane Edna), 3,340 cfs; October 1955, 2,800 cfs; March 1948, 2,560 cfs; and June 1948, 2,410 cfs.

The maximum discharge recorded in the Pawcatuck River basin was 4,470 cfs on March 18, 1968. The minimum discharge, August 17, 1941 was 25 cfs and in 36 years of records the average daily discharge was 563 cfs.

Summer low flows of the Pawcatuck River basin streams are derived almost entirely from natural discharges from ground water resources. The area above the gage on the Pawcatuck River near Wood River Junction has swamp areas amounting to about 14 percent of the total drainage area and numerous ponds which result in slow runoff and low discharge peaks. The meandering course of the Pawcatuck River and the large areas of swamp south of the river account for the slow runoff and low discharge peaks at the Westerly gage.

WOONASQUATUCKET RIVER BASIN

The Woonasquatucket River Basin lies entirely within the north-northwestern portion of Rhode Island. It has a total drainage area of 75.2 square miles. It flows into the Providence River, about 0.2 miles north of the Fox Point Hurricane Barrier in Providence. The basin is irregular in shape and is comprised of two major streams. The watershed's maximum length is 14 miles with a width of 9 miles.

The waterways of the basin were originally developed for textile manufacturing and processing. The needs of the textile industry were met by the conservation storage from over 30 impoundments throughout the watershed. Fifteen of these impoundments have a surface area greater than 20 acres and total 1,224 acres of water surface area.

The southern third of the basin is located in the upper Providence metropolitan area, a very highly urbanized commercial-industrial-residential area. It is this area that has suffered the most significant flood problems. The middle third of the basin is undergoing a transition from rural to urban whereas the upper third is largely rural with several small villages located in proximity to the transportation facilities.

The watershed is bounded by the Blackstone River Basin on the north and east, the Pawtuxet on the south and west, with a small portion touching the Narragansett Bay Local Drainage Area on the southeast. A detailed basin map is shown on Plate 1-5.

The Woonasquatucket River itself is principally located within the municipalities of Smithfield, Johnston, North Providence and Providence. It originates in North Smithfield and flows in a southerly direction into Stillwater Reservoir where it is joined by the Stillwater River. The river then flows in a similar direction through several mill ponds (Georgiaville Pond, Stillwater Pond and Capron among the largest). The maximum river length is 19 miles. The Woonasquatucket is joined by its principal tributary the Moshassuck, at a distance of 1.2 miles above its mouth. The total drainage of the Woonasquatucket itself is slightly above 51.5 square miles. The U.S. Geological Survey maintains a stream gage at Centerdale near U.S. Highway 44 where the upstream area is 38.4 square miles. The basin ranges in elevation from sea level up to 260 feet.

The Stillwater River is 8.3 miles long and has a drainage area of 17 square miles. It has an average slope of 28 feet per mile in its 8.3 mile length.

During normal flow, the Woonasquatucket River falls approximately 190 feet over the rivers length, with an average slope of about 12 feet per mile.

Moshassuck River, the major tributary of the Woonasquatucket has a drainage area of 23.3 square miles and is in the eastern portion of the overall watershed. It has its headwaters in the rural portion of Lincoln and Smithfield. It has a maximum water length of about 9.5 miles and flows down through the western portions of Pawtucket and North Providence. The U.S. Geological Survey also maintains a stream gage within this sub-basin at a point .5 mile above the confluence point with the Woonasquatucket, and has an upstream drainage area of 23.1 square miles. The Moshassuck River is joined by its principal tributary, the West River at river mile 1.3.

The lower half of the Moshassuck sub-basin is located in a very densely populated area with above normal concentrations of both industrial and commercial firms. Fortunately, little development has occurred within areas subject to flooding from a 25 year event, and only minor development within the 100-year limits. The upper half of the sub-basin consists mainly of residential development interspersed with commercial centers. A new airport, the North Central State Airport, has recently been constructed and is now operational. A new industrial complex is a major component of this airport park. This area is in the extreme headwaters of the basin.

The elevations of the Moshassuck range from just above sea level up to about 400 feet. The average slope of the river is about 23 feet per mile.

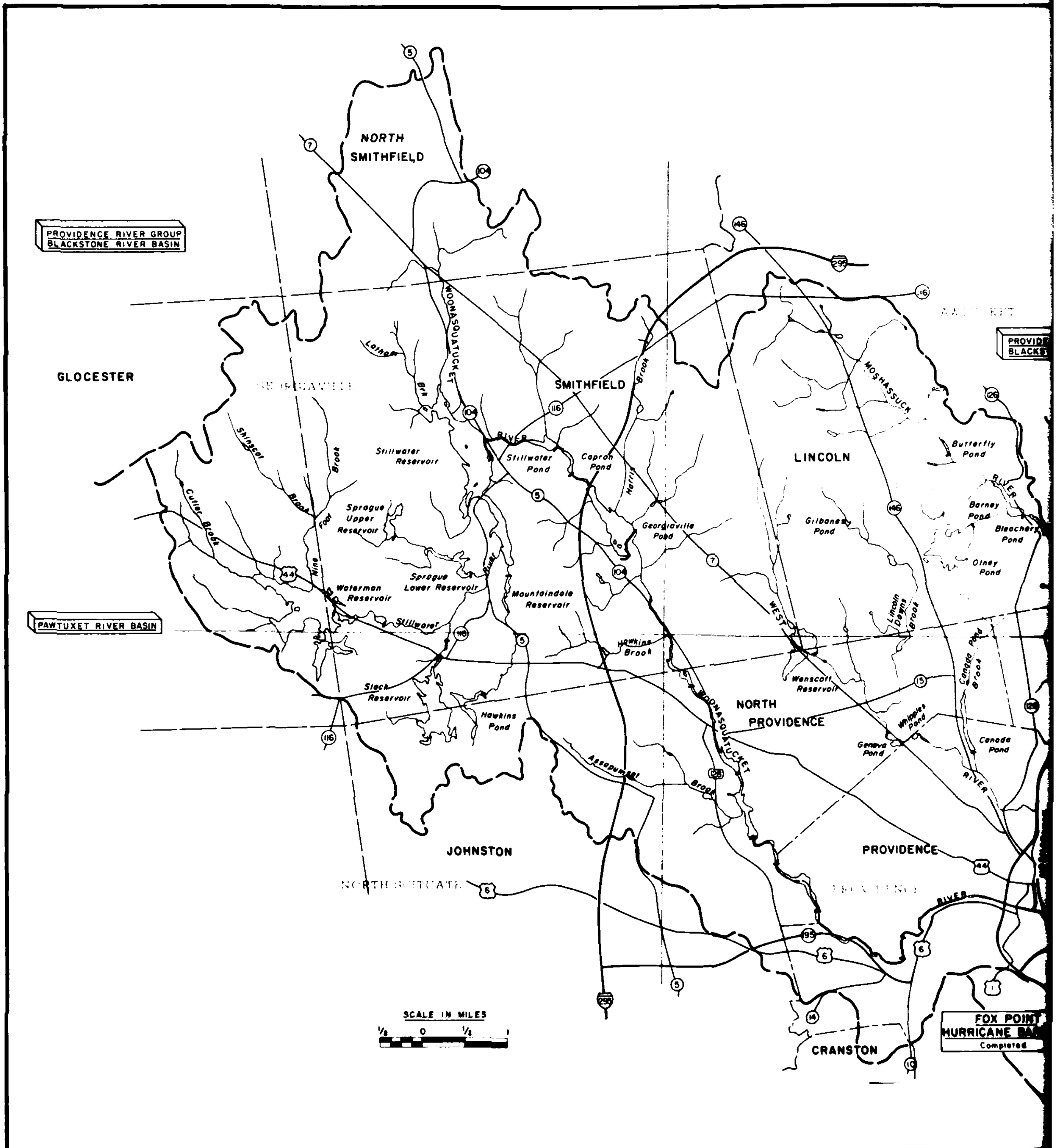
TABLE 1-5

GAGE STATION RECORDS

MONTHLY DISCHARGE IN CUBIC FEET/SECOND

WATER YEAR 1977

	Pawcatuck River at Westerly, R.I. Drainage Area - 295 sq.mi.			Woonasquatucket River at Centerdale, R.I. Drainage Area - 38.3 sq.mi.			Moshassuck River at Providence, R.I. Drainage Area - 23.1 sq.mi.		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
October	185	325	124	58.2	159	73	32.4	149	13
November	190	221	179	47.0	65	33	20.3	28	17
December	292	382	191	82.8	140	33	24.8	88	16
January	395	650	250	47.9	104	30	37.4	181	17
February	418	1150	300	45.3	119	32	43.0	221	21
March	1424	2360	925	198	476	75	93.2	243	59
April	1167	2360	670	134	304	64	61.5	257	34
May	639	1250	348	97.4	235	44	43.7	147	17
June	366	670	244	46.4	75	35	27.2	100	15
July	183	259	141	24.9	33	21	14.3	93	8.1
August	143	221	107	20.4	28	18	11.9	35	7.0
September	226	480	110	72.7	120	19	29.9	113	7.3
Water Year 1977	469	2360	107	73.1	476	18	36.6	257	7.0
Average Discharge	563 cfs (36 Years of record)			71.3 cfs (36 Years of record)			39.7 cfs (14 years of record)		
Maximum Discharge	4,470 cfs (March 18, 1968)			1,440 cfs (March 18, 1968)			2,390 cfs (March 18, 1968)		
Minimum Daily	25 cfs (August 17, 1941)			2.1 cfs (August 26,1963)			1.7 cfs (August 10, 1970)		



PROVIDENCE RIVER GROUP
BLACKSTONE RIVER BASIN
NORTH SMITHFIELD
GLOCESTER
SMITHFIELD
LINCOLN
PAWTUXET RIVER BASIN
NORTH PROVIDENCE
JOHNSTON
PROVIDENCE
CRANSTON
WOONASQUATUCKET
MOSHASSUCK
RIVER
WEST RIVER
Stillwater Reservoir
Stillwater Pond
Capron Pond
Sprague Upper Reservoir
Sprague Lower Reservoir
Waterman Reservoir
Slack Reservoir
Hawkins Pond
Hawkins Brook
Mountaindale Reservoir
Georgiaville Pond
Gilbanes Pond
Wenscott Reservoir
Geneva Pond
Whipples Pond
Canada Pond
Canada Pond Brook
Butterfly Pond
Barney Pond
Bleachery Pond
Olney Pond
Lincoln Downs Brook
Harris Brook
Shinscot Brook
Cutler Brook
Nine Foot Brook
Latham Brk
Assapumsset Brook
SCALE IN MILES
1/2 0 1/2 1
FOX POINT
Completed

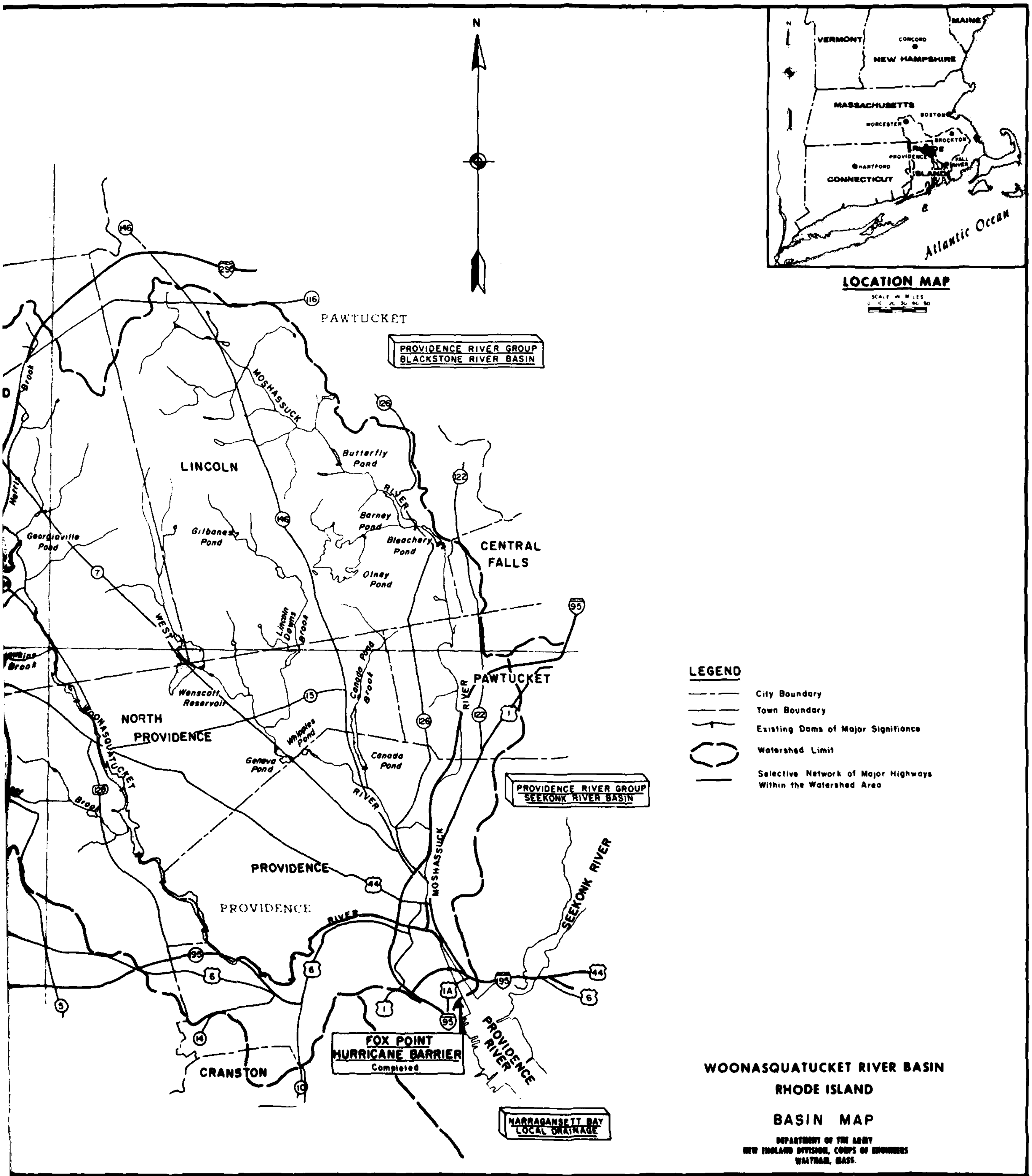

N
LOCATION MAP
SCALE IN MILES
VERMONT
NEW HAMPSHIRE
MAINE
CONCORD
MASSACHUSETTS
BOSTON
WORCESTER
BROCKTON
PROVIDENCE
HARTFORD
CONNECTICUT
FALL RIVER
Atlantic Ocean
PAWTUCKET
PROVIDENCE RIVER GROUP
BLACKSTONE RIVER BASIN
MOSHASSUCK
Butterfly Pond
LINCOLN
RIVER
Barney Pond
Gilbanes Pond
Bleachery Pond
Olney Pond
CENTRAL FALLS
Georgiaville Pond
WEST
Lincoln Downs Brook
Canada Pond Brook
PAWTUCKET
Wenscott Reservoir
NORTH PROVIDENCE
Whipples Pond
Geneva Pond
Canada Pond
WOONASQUATUCKET
PROVIDENCE RIVER GROUP
SEEKONK RIVER BASIN
RIVER
MOSHASSUCK
PROVIDENCE
SEEKONK RIVER
PROVIDENCE
RIVER
FOX POINT
HURRICANE BARRIER
Completed
PROVIDENCE RIVER
CRANSTON
NARRAGANSETT BAY
LOCAL DRAINAGE
LEGEND
City Boundary
Town Boundary
Existing Dams of Major Significance
Watershed Limit
Selective Network of Major Highways Within the Watershed Area
WOONASQUATUCKET RIVER BASIN
RHODE ISLAND
BASIN MAP
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.

PLATE 1-5

2

The West River is the major tributary of the Moshassuck. It originates in the swampy area of the southern part of Lincoln and Smithfield. It flows for a length of 6.8 miles in a southeasterly direction. The sub watershed has a total drainage area of about 11 square miles. The West River is comprised of two small principal tributary streams; Canada Pond Brook; and Lincoln Downs Brook. Elevations range from 20 feet NGVD (National Geodetic Vertical Datum) at the confluence with the Moshassuck up to above 410 feet NGVD. Excluding vertical falls at several structures, the average slope is about 55 feet per mile. The total length of the West River is 6.8 miles.

Development in the West River area has been occurring at a high rate. The upper portion of the sub-basin is primarily residential with the recent appearance of small commercial centers to serve the new airport park. The lower portion is heavily industrialized. Significant flood prone structures are evident. A dominant feature of the sub-basin is Wenscott Reservoir which is used primarily for recreational usages.

Lincoln Downs Brook has a small drainage area, 2.3 square miles, a maximum length of 3.9 miles with an average slope of 64 feet per mile. Canada Pond Brook is even smaller with an area of only 1.5 square miles and a length of 2.3 miles. Its average slope is about 60 feet per mile. The Lincoln Downs and Canada Pond Brooks present a minor flood threat due to increased urbanization and inadequate local drainage facilities. With these relatively high slopes, the runoff is fairly rapid leading to a high volume of flow. If an inadequate bridge or culvert opening blocks a portion of the flow regime a backup of waters will occur and will rise until the runoff/discharge relation through the opening is equal or until the water flows over the obstruction.

NARRAGANSETT BAY LOCAL DRAINAGE

Narragansett Bay is located in the eastern portion of Rhode Island. The Narragansett Bay area consists of the system of interconnected waterways that discharge into the Atlantic Ocean off of the south shore of Rhode Island between Point Judith on the west and Sakonnet Point on the east. The total land and water area of the 26 cities and towns (19 in Rhode Island and 7 in Massachusetts) located along the shores of the bays and the banks of their tidal tributaries is approximately 710 square miles. The bay area is shown on Plate 1-6.

The total water area of the bays is about 154 square miles. Three large islands, Aquidneck, Conanicut, and Prudence and about six smaller islands are located within the bay. Conanicut and Prudence Islands divide the main portion of Narragansett Bay into two long and narrow passages known as the East and West Passages. Aquidneck Island separates the East Passage from the Sakonnet River to the east. This latter river provides an alternate shallow draft entrance or passage at Mount Hope Bay. To the south and southeast the bay lies directly exposed to the Atlantic Ocean, making it vulnerable to hurricane surges sweeping up the coast. The

shoreline is characteristically irregular and marked by numerous sandy beaches, inlets, and bold rocky shores. Much of the shore has been developed for varying degrees of residential, commercial, and industrial uses and former military installations. These military installations which provided numerous jobs to the economy of the area are now for the most part inactive. Some private development has occurred at the former Navy installation at Kingston.

In Rhode Island the city of Newport is located just inside the entrance to the East Passage and the city of Providence is at the head of the bay. The principal Massachusetts city in the bay area, Fall River, is situated at the head of Mount Hope Bay.

The major tributaries to Narragansett and Mount Hope Bays are the Pawtuxet River Basin, the Woonasquatucket-Moshassuck River Basin, the Blackstone River Basin, the Ten Mile River Basin and the Taunton River Basin. Separate interim reports have been prepared for the Blackstone, Pawtuxet and Taunton River Basins.

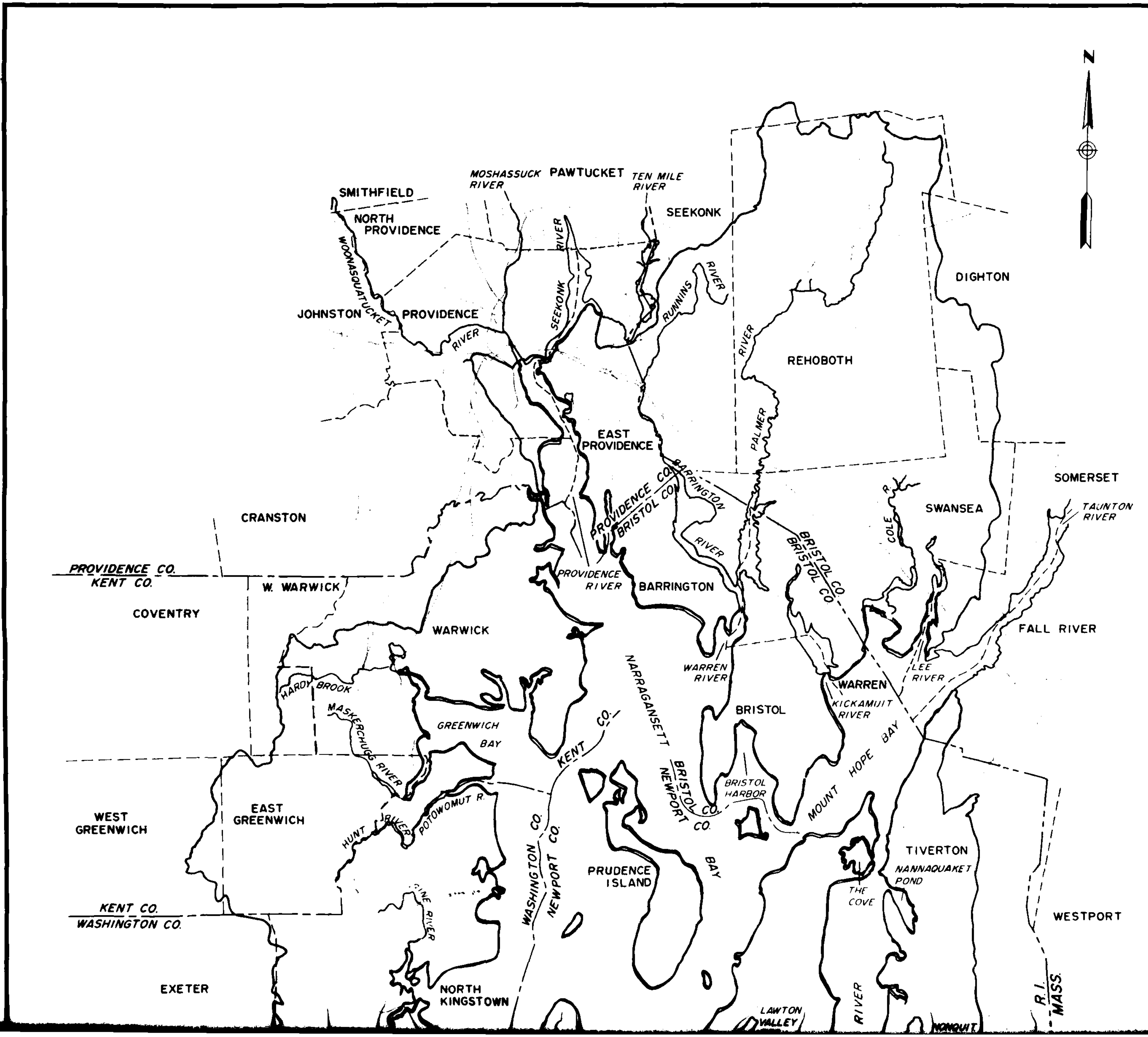
The Pawtuxet River Basin drains a total area of 230 square miles. It rises in the hilly western uplands along the Rhode Island-Connecticut State line and meanders through numerous swamps, ponds and lakes, before discharging its waters into Pawtuxet Cove a tidal estuary of the Providence River. Major tributaries of the Pawtuxet River are the North Branch, South Branch, Meshanticut Brook and the Pocasset River.

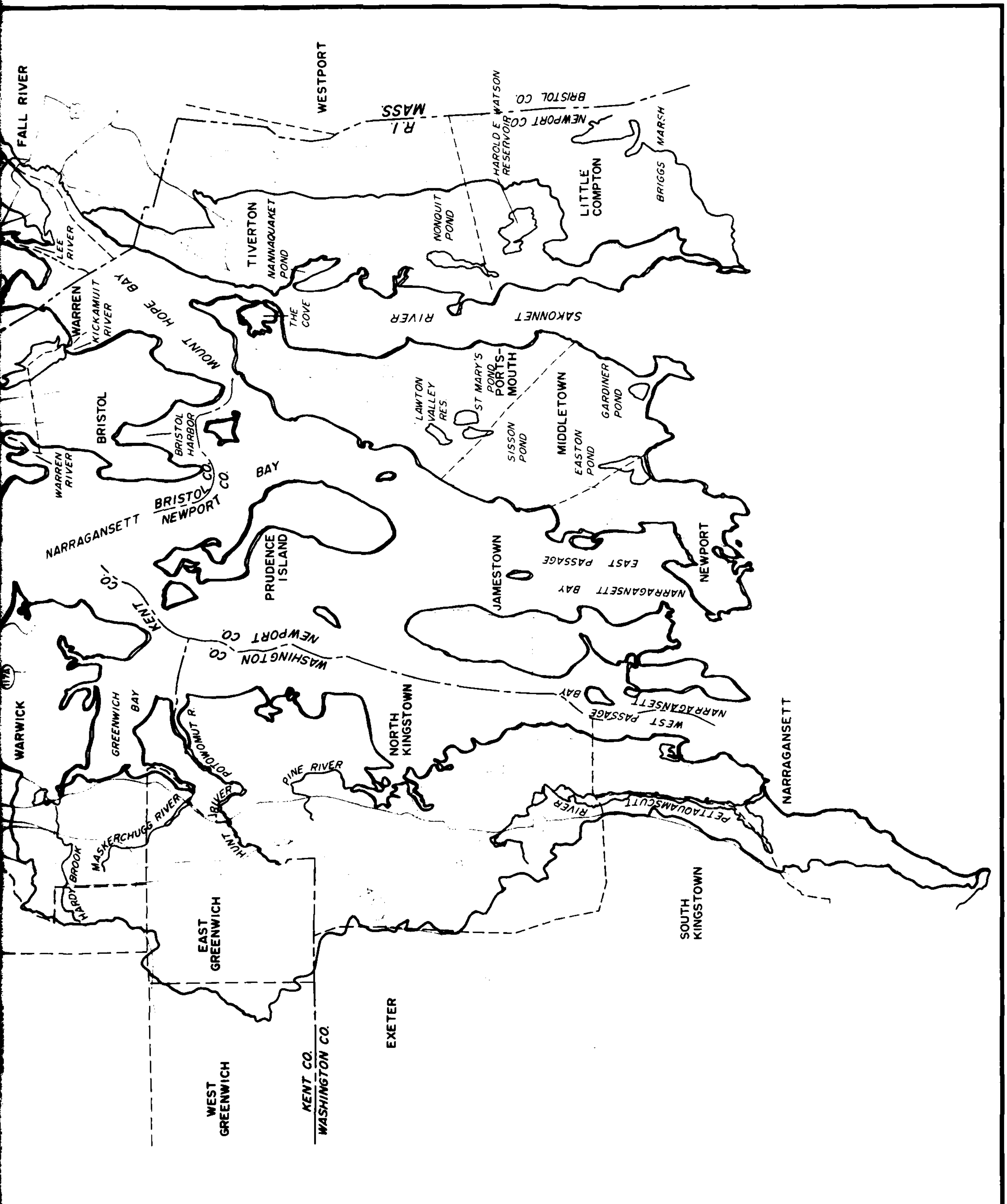
The Woonasquatucket River and the Moshassuck River have been described on pages 1-13 and 1-14.

The Blackstone River Basin extends through south central Massachusetts and Northern Rhode Island and covers approximately 334 and 142 square miles respectively in each state. It originates at the confluence of the Middle River and Mill Brook on the southeastern part of the city of Worcester, Massachusetts. The river is approximately 44 miles long from its confluence to its mouth, the upper 27 miles in Massachusetts and the lower 17 in Rhode Island.

Tributaries of significance are the headwater streams (Kettle, Beaver and Mill Brooks and the Middle River), the Quinsigammond West, Mumford, Branch, Mill and Peter Rivers and Abbott Run.

The Ten Mile River originates in Massachusetts near the Wrentham-Plainville town line. It flows through three Massachusetts communities and East Providence Rhode Island before discharging into the Seekonk River in the township of Rumford. [The Seekonk River is a tidal extension of the Blackstone River.] Tributaries of significance are the Bungay and Seven Mile Rivers. The total drainage area of the Ten Mile River Basin is approximately 55 square miles.


N
SMITHFIELD
NORTH PROVIDENCE
MOSHASSUCK RIVER
PAWTUCKET
TEN MILE RIVER
SEEKONK
WOONASQUATUCKET
JOHNSTON
PROVIDENCE
RIVER
SEEKONK RIVER
RUNNINS RIVER
RIVER
REHOBOTH
DIGHTON
PALMER
EAST PROVIDENCE
CRANSTON
PROVIDENCE CO.
KENT CO.
PROVIDENCE CO.
BRISTOL CO.
BARRINGTON RIVER
SOMERSET
SWANSEA
COLE R.
TAUNTON RIVER
BRISTOL CO.
BRISTOL CO.
PROVIDENCE RIVER
BARRINGTON
W. WARWICK
COVENTRY
WARWICK
FALL RIVER
WARREN RIVER
NARRAGANSETT
WARREN
LEE RIVER
KICKAMUIT RIVER
HARDY BROOK
MASKERCHUGG RIVER
GREENWICH BAY
KENT CO.
BRISTOL
MOUNT HOPE BAY
BRISTOL CO.
NEWPORT CO.
BRISTOL HARBOR
WEST GREENWICH
EAST GREENWICH
HUNT RIVER
POTOWOMUT R.
WASHINGTON CO.
NEWPORT CO.
PRUDENCE ISLAND
BAY
TIVERTON
NANNAQUAKET POND
THE COVE
KENT CO.
WASHINGTON CO.
WESTPORT
EXETER
NORTH KINGSTOWN
LAWTON VALLEY
RIVER
R.I.
MASS.


FALL RIVER
WESTPORT
R.I.
MASS.
BRISTOL CO.
NEWPORT CO.
HAROLD E. WATSON RESERVOIR
LITTLE COMPTON
BRIGGS MARSH
TIVERTON
NANNAQUAKET POND
NONQUIT POND
LEE RIVER
WARREN
KICKAMUIT RIVER
MOUNT HOPE BAY
THE COVE
SAKONNET RIVER
BRISTOL
BRISTOL HARBOR
LAWTON VALLEY RES.
ST MARY'S POND
PORTSMOUTH
MIDDLETOWN
GARDINER POND
SISSON POND
EASTON POND
WARREN RIVER
NARRAGANSETT BAY
BRISTOL CO.
NEWPORT CO.
PRUDENCE ISLAND
JAMESTOWN
EAST PASSAGE
NEWPORT
NARRAGANSETT BAY
KENT CO.
NEWPORT CO.
WASHINGTON CO.
WARWICK
GREENWICH BAY
POTOWOMUT R.
NORTH KINGSTOWN
WEST PASSAGE
NARRAGANSETT BAY
NARRAGANSETT
PINE RIVER
HUNT RIVER
MASKERCHUGG RIVER
HARDY BROOK
PETTAQUAMSCUTT RIVER
EAST GREENWICH
SOUTH KINGSTOWN
EXETER
KENT CO.
WASHINGTON CO.
WEST GREENWICH

2

PLATE 1-6

The Taunton River Basin lies principally within southeastern Massachusetts with a small portion on eastern Rhode Island. It has a total drainage area of 570 square miles and discharges to Mount Hope Bay at Brayton Point in Somerset, Massachusetts. The river is slightly over 38 miles in length and is formed by the confluence of the Town and Matfield Rivers. The Taunton River is also joined by six other major tributaries--The Winnetuxet, Nemasket, Mill, Threemile, Assonet-Cedar Swamp, and the Quequechan Rivers.

The Lee River, a tidal estuary, flows 2.7 miles to Mount Hope Bay. Surrounded by a predominantly residential area, the river is the Swansea-Somerset town line. It has a drainage area of 6.6 square miles and a maximum length of 4.6 miles. Several small streams and Lewin Brook are tributaries to the Lee River.

The Cole River rises in the wetlands of the southeast portion of Dighton at an elevation of 90 feet NGVD (National Geodetic Vertical Datum). It flows 8.3 miles through the wetlands and forests of Dighton and Milford Pond in Swansea before discharging its water to Mount Hope Bay. It is a relatively undeveloped basin with the exception of the Ocean Grove section of Gardners Neck, at the mouth of the river. Its total drainage area is 17.0 square miles, the maximum length 9.1 miles and the average slope is 12 feet/mile.

The Kickamuit River flows 4.3 miles from the Warren Reservoir in Swansea across the Massachusetts-Rhode Island state line to Mount Hope Bay at Bristol Narrows. It drains an area of about 8.5 square miles. The maximum length is 5.8 miles and the average slope from an elevation of 50 feet NGVD to sea level is 12.8 feet/mile. The upper portion of the Kickamuit River Basin is a rural area with many small swamps. The lower basin, particularly the western shoreline of the river, is a thickly settled residential neighborhood.

The Palmer River originates in Rehoboth and flows through a hilly, wooded region, southerly, to the Warren River which is in a densely populated area of Warren and Barrington. The Palmer River watershed includes many small tributary streams and swamps. The Palmer and Warren Rivers have a combined length of 12.9 miles and a drainage area of 51.6 square miles. The Palmer River flows from an elevation of 110 feet NGVD to sea level and has an average slope of 11.9 feet/mile.

The Runnins River, originating in Seekonk, flows in the Massachusetts-Rhode Island state line where it becomes the Barrington River which later joins the Warren River. The Runnins and Barrington Rivers have a combined length of 12.0 miles and a total drainage area of 16.4 square miles. The Runnins River flows alternately through wetlands and residential areas and its basin area includes a few small tributaries and ponds. The upper portion of the Barrington is comprised of tidal

flats and salt water marshes. Hundred Acre Cove is also located in this upper portion. The lower portion of the Barrington is in a densely populated urban area. The Runnins River has an average slope of approximately 12.5 feet/mile.

Hardig Brook with a drainage area of 6.0 square miles, flows 4.0 miles through Warwick in an easterly direction to its outlet at Apponaug Cove. The brook flows through primarily suburban areas from its origin at an elevation of 240 feet NGVD in a swampy area of West Warwick to the cove, with a few small streams joining it along the way. The average slope of Hardig Brook is about 60 feet/mile.

The Maskerchugg River has its beginnings at an elevation of 210 feet NGVD in a hilly region of Warwick. It then flows 3.8 miles in a southeasterly direction through an urban section of East Greenwich to Bleachery Pond and then to Greenwich Cove. The average slope of the river is 67 feet/mile. The area of the Maskerchugg River basin is 5.2 square miles.

The Hunt River originates in a swampy area of North Kingston and continues through the swamp where it becomes the East Greenwich-North Kingstown town line. Approximately 1 mile downstream from the Potowomut Pond, the Hunt River becomes the Potowomut River discharging directly to Narragansett Bay. The combined drainage area is 26.0 square miles and the length of the Hunt and Potowomut Rivers is 7.5 miles with a maximum length of 11.5 miles. The average slope of the Hunt River is 8.3 feet/mile. Most of the watershed is sparsely populated with the exception of 2 areas: the area surrounding Potowomut Pond and the area southwest of Greenwich Cove.

The Pine River/Mill Creek watershed encompasses a large portion of the former Quonset Point U.S. Naval Reservation in its 3.5 square mile area. The combined length of Pine River and Mill Creek is 3.2 miles. The Pine River/Mill Creek watershed is essentially a wooded, sparsely populated area. The Pine River has its beginnings in a swampy area of North Kingston. The average slope of Pine River and Mill Creek is 15.6 feet/mile.

The Annaquatucket River, with a drainage area of 7.3 square miles, flows easterly for 4.0 miles, from the State Fish Hatchery through Belleville Pond to Bissel Cove. The Annaquatucket originates in a hilly region of Kingston and has an average slope of 15.4 feet/mile. The watershed is sparsely populated and characterized by many small hills and swamps.

Pettaquamscutt River begins at Carr Pond in North Kingston and flows southerly to the Narrows, its outlet to Narragansett Bay. Draining an area of 14.0 square miles, the Pettaquamscutt is 3.5 miles long and has a maximum length of 7.0 miles. Pettaquamscutt Cove extends to the southeast as a long, narrow arm of the river. Crooked Brook flows northward from the wetlands at the southern tip of the watershed to the cove. At the

northern end of the watershed, the Mattatuxet River extends from Silver Spring Lake to Carr Pond. The western shoreline of the Pettaquamscutt is mainly steep hills while the east is a wooded, residential area.

The shoreline of the bay is comprised of many harbors, bays and coves. Several of these areas are used extensively for mooring of fishing and recreational boats. Pawtuxet Cove lies along the Cranston-Warwick city line at the mouth of the Pawtuxet River at the west side of the Providence River. Bullocks Point Cove, 5 miles southeast of Providence, lies on the east side of the Providence River opposite Pawtuxet Cove at the head of Narragansett Bay. Greenwich Bay, lying 9 miles south of Providence, is a westward arm of Narragansett Bay. Warwick Cove, Brush Neck Cove and Buttonwoods Cove are narrow inlets extending northward from Greenwich Bay. Apponaug Cove, at the northwestern tip of Greenwich Bay, is divided into three areas known as the outer, middle, and inner basins. Greenwich Cove, a long narrow inlet is at the southwestern tip of Greenwich Bay.

Wickford Harbor is located on the west shore of Narragansett Bay about 17 miles south of Providence. It consists of an outer harbor and three small coves - Fishing Cove to the north, Mill Cove to the northwest and Wickford Cove to the southwest. Bristol Harbor, on the east side of Narragansett Bay, is about 13 miles southeast of Providence. Bristol Harbor is actually a cove, separated from Mt. Hope Bay by Bristol Neck on the east and from Narragansett Bay by Popasquash Neck on the west.

Coasters Harbor is a small protected harbor located between the northeastern side of Coasters Harbor Island and the peninsula at the northwestern end of the city of Newport. Newport Harbor is on the east side of the main entrance to Narragansett Bay between Goat Island and the western shore of the city of Newport. Brenton Cove is located at the southwest end of Newport Harbor. Sachuset Bay and Easton Bay are situated along the southern shoreline of Aquidneck Island at the entrance to Narragansett Bay. The Cove, on the Sakonnet River in Portsmouth, is between the Hummocks to the north and Island Park to the south. Dutch Island Harbor is along the eastern shoreline of Conanicut Island between Beaver Neck and the main portion of the island.

Fall River Harbor, situated at the mouth of the Taunton River, extends into the eastern half of Mt. Hope Bay, which is open to the Atlantic Ocean through both Narragansett Bay and the Sakonnet River. Sakonnet Harbor and Church Cove are located on the east side of the entrance to the Sakonnet River, about 0.4 miles north of Sakonnet Point and about 7 miles east of Newport. Sakonnet Point is considered to be the eastern entrance point to Narragansett Bay.

The sandy beaches along the coastline of Narragansett Bay are used extensively for recreational purposes. The most notable of these beaches are Narragansett Beach, Bonnet Shores Beach, Bailey Beach, Easton Beach and Second Beach. Narragansett Beach, located in the town of Narragansett

along the western coastline of the bay, has three beach clubs and has been a popular resort area for many years. There is another beach club at the Bonnet Shores Beach, also in Narragansett. Bailey Beach, Easton Beach and Second Beach are all situated along the southern coastline of Aquidneck Island. The famous Cliff Walk in Newport extends from Easton Beach to Bailey Beach. Second Beach is located in Sachuset Bay about 1 mile east of Easton Beach.

Aquidneck Island is chiefly a residential/resort area characertized by rolling hills, many small streams, and several relatively large ponds. Island Park, in Portsmouth, is a residential, low-lying region along the north shoreline of the Sakonnet River. Numerous shops and restaurants are along the Newport Harbor Waterfront. These are in a low, flat area and many are located right on the piers. There is a causeway from Newport to Goat Island where a hotel, restaurant, resort-type complex has recently been built. Goat Island is extremely low and narrow.

Conanicut is a long, narrow island separating the East and West Passages of Narragansett Bay. It is a hilly island with a few small streams and swamps and scattered residential neighborhoods. Beaver Neck is connected to the main island by Mackeral Cove Beach. Very few homes are located on either Prudence Island or Patience Island; both located north of Conanicut. The southern tip of Prudence Island is a U.S. Naval Reservation.

The Little Compton/Tiverton shoreline of the Sakonnet River is a rural area with several large swamps. The most significant of these are the Basket and Cedar Swamps, which are drained by Border Brook to Nonquit Pond. The only other notable pond in the area is Nannaquatucket Pond. The Sapowet Marsh Wildlife Preserve is situated between these two ponds.

The shoreline of Mount Hope Bay, to the east, is urban (Fall River), while the west, in Bristol and Warren, is suburban. The northern shoreline of Narragansett Bay - Rumstick Neck, Pasquash Neck and Bristol Neck - is also primarily suburban.

Heavily developed commercial and industrial districts line each side of the Providence River and Harbor. The local drainage within Warwick includes the Theodore Francis Green Memorial Airport; the remainder of that section is principally residential. Tuscatucket Brook, Buckeye Brook, and Knowles Brook are the waterways draining this area; Warwick Pond is the only significant body of water.

The U.S. Naval Reservation in North Kingston is situated along the western coastline of the bay. The Black Swamp, also in North Kingston, is drained by the Cocumcussoc Brook which discharges its waters to Mill Cove. Wannuchecumcut Brook flows to Bissel Cove, south of Wickford Harbor. The rocky coastline of Narragansett has several small streams flowing directly to the bay.

TABLE 1-6

PAWCATUCK RIVER & NARRAGANSETT BAY
DRAINAGE BASINS
TOTAL AREA

River Basin	Area in Square Miles
Providence Group	
Woonasquatucket - Moshassuck	75.2
Blackstone	476.0
Ten-Mile	55.0
Pawtuxet	230.0
Taunton	570.0
Lee	6.6
Cole	17.0
Kickamuit	8.5
Annaquatucket	7.3
Pettaquamscutt	14.0
Maskerchugg	5.2
Warren & Palmer	51.6
Barrington & Runnins	16.4
Potowomut & Hunt	26.0
Pine	3.5
Hardig Brook	6.0
Local Drainage	147.7
Approx. Water Area Narragansett Bay, Providence River, & Mt. Hope Bay	153.9
SUBTOTAL	1870.0 sq. mi.
Pawcatuck River	303.0
TOTAL PNB AREA	2173.0 sq. mi.

The local drainage area is approximately 148 square miles and the total Narragansett Bay land and water area is 1870 square miles.

CLIMATOLOGY

The Woonasquatucket and Pawcatuck Basins, and Narragansett Bay local drainage area lie within the southeastern New England region, a humid area with an average annual precipitation of between 39 and 48 inches rather evenly distributed throughout the year. It has a variable climate characterized by frequent but generally short periods of precipitation produced by local thunderstorms and by intense "lows" of tropical and extratropical origin that move northeasterly up the coast. The area also lies in the path of the prevailing "westerlies" which generally travel across the country in an easterly or northeasterly direction producing frequent weather changes. Because Narragansett Bay has a moderating effect, the study areas escape the severity of cold and greater depth of snowfall experienced in the higher elevations of the interior areas of New England.

Temperature - The average annual temperature within the study area is about 50° Farenheit (F). Extremes in temperature range from occasional highs at 100°F to lows of -15°F. Freezing temperatures may be expected from the latter part of October until the middle of April. The mean, maximum and minimum monthly temperatures and annual mean temperatures for the periods of record in three representative areas are shown in Tables 1-7 through 1-9.

Precipitation - The mean annual precipitation in the watershed area varies from about 39 inches in the lower coastal area to about 48 inches in the uplands. The distribution of the precipitation is quite uniform throughout the year. However, extremes in monthly values range from a high of more than 16 inches to less than 0.20 inch on several occasions. The monthly and annual records of precipitation at Providence, RI, representative of the upper coastal area, are shown in Table 1-7; records for precipitation at Groton, CT, and Kingston, RI, representative of the Pawcatuck Basin, are shown in Tables 1-8 and 1-9. The heaviest precipitation recorded at New London, CT, for a 24-hour period was 5.20 inches on 23-24 October 1923. This may have been exceeded during the hurricane of September 1938, at which time the rain gage was destroyed.

Snowfall - The average annual snowfall over the Rhode Island - Connecticut region in Table 1-10 ranges from 25 to 38 inches. Water content of the snow cover usually reaches a maximum about the first of March but rarely exceeds 2 to 3 inches due to the moderating effect of Narragansett Bay.

Snowcover - Water equivalent of snow cover is recorded at various locations throughout New England by the Corps of Engineers. In southern New England the closest recording site to the area is located in the

Blackstone River Basin roughly 40 miles to the northeast of the northernmost boundary of the study area. The data listed in Table 1-11 is considered applicable only to the more interior northern portions of the basin. Wide variation of water equivalent snowcover can reasonably be expected as one travels from the interior to the coastal areas. Lack of a substantial snow cover near the coast is due to the milder temperatures influenced by Narragansett Bay; snow fall is approximately half of that experienced in the interior.

Storms - There are three general types of storms that cause precipitation over the watershed, namely, continental storms, coastal storms and local thunderstorms. Continental storms originate over the western or central regions of the United States and move in a generally easterly or northeasterly direction. These storms may be rapidly moving intense cyclones or stationary frontal storms. They are not limited to any season or month, but follow one another at more or less regular intervals with varying intensities throughout the year.

Extratropical coastal storms generally originate near the Middle Atlantic States and then travel northward along the coastline. These storms occur most frequently during the autumn, winter and spring months. Such storms can develop into "northeasters" which can stall near or off the New England coast for several days.

Tropical storms, the most severe of the coastal storms, originate in the South Atlantic Ocean or Caribbean Sea. They usually move in a westerly direction and then recurve along a northerly path as they approach the United States mainland. Although most hurricanes as they approach New England follow a northeasterly path and generally pass to the south and east of New England, they may be drawn over the New England area by continental cyclonic disturbances or deflected by a large, slow moving anti-cyclone center ("blocking high") located to the east of New England. The lower reaches of the Woonasquatucket River basin, once susceptible to the tidal flooding that usually accompanies tropical hurricanes, are now protected by the Fox Point Hurricane Barrier. The only potential damages that could occur as a rsult of tropical storms would be the accompanying rainfall causing possible riverine flooding along the Woonasquatucket River. A hurricane flood protection project was completed in September 1963 on the west bank of the Pawcatuck River lower reaches. It affords protection to an adjacent industrial area from tidal flooding that accompanies hurricanes. The Narragansett Bay Local Drainage Area is extremely vulnerable to damage caused by hurricanes and tropical storms.

Thunderstorms can be produced by local convective activity during the warm humid days of the summer months or be associated with a frontal system moving across the watershed. Such storms can produce local flooding on tributary streams or more general flooding should abnormal streamflows and saturated surface conditions exist prior to the occurrence of intense thunderstorms.

TABLE 1-7

MONTHLY TEMPERATURE AND PRECIPITATION
AT PROVIDENCE, RHODE ISLAND

	TEMPERATURE (Degrees Fahrenheit)			PRECIPITATION (Depth in Inches)		
Month	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	29.8	67	-7	4.04	8.61	.50
February	29.8	68	-17 (1)	3.62	11.98	.43
March	37.4	84	3	4.20	10.96	.35
April	46.9	91	13	3.76	10.85	.64
May	57.4	93	38	3.49	9.03	.54
June	66.2	97	31	3.09	7.71	.01 (1949)
July	71.7	99	44	3.53	7.13	.44
August	70.3	100 (2)	44	4.39	16.44 (1874)	.48
September	64.4	95	35	3.41	11.21	.33
October	54.3	87	24	3.52	8.47	.20
November	43.4	77	9	3.83	9.40	.32
December	33.0	67	-12	3.77	10.67	.73
ANNUAL	50.4	100	-17	44.61	60.62 (1919)	30.05 (1896)

(1) February 9, 1934 (2) August 26, 1948

TABLE 1-8

MONTHLY TEMPERATURE AND PRECIPITATION
GROTON, CONNECTICUT

	Temperature 1957-1976			Precipitation 1941-1976		
Month	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	28.0	65	-14 (1/22/61)	4.25	9.68	0.74
February	29.0	67	-12	3.92	6.73	1.66
March	36.6	66	0	4.46	9.63	1.72
April	46.3	84	16	3.95	8.60	0.80
May	55.6	87	29	3.78	8.20	0.78
June	65.0	95	38	2.74	9.90	0.03 (1949)
July	70.7	97	49	3.20	6.82	0.46
August	70.0	99 (8/2/75)	41	3.89	12.63 (1952)	0.73
September	63.1	91	29	3.42	9.31	0.14
October	52.9	83	22	3.48	8.52	0.26
November	43.4	74	13	4.80	9.12	0.57
December	32.1	67	-10	4.87	9.71	0.81
ANNUAL	49.4			46.86	68.03 (1972)	31.33 (1965)

TABLE 1-9

MONTHLY TEMPERATURE AND PRECIPITATION
KINGSTON, RHODE ISLAND

Month	TEMPERATURE (Degrees Fahrenheit)			PRECIPITATION (Depth in Inches)		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	28.1	68	-23 (1/1/42)	4.41	11.43	0.83
February	28.2	66	-22	3.98	9.44	0.67
March	35.9	82	-10	4.53	10.07	0.23
April	45.1	89	8	4.29	9.70	0.72
May	55.1	93	25	3.86	8.95	0.67
June	64.0	96	30	3.20	9.97	0.04 (1949)
July	69.5	98	38	3.16	11.75	0.43
August	68.3	100 (8/3/75)	24	4.23	12.56 (1952)	0.79
September	62.0	95	25	3.79	12.66	0.35
October	52.1	87	13	3.81	12.05	0.27
November	41.6	76	4	4.48	10.25	0.41
December	31.3	66	-17	4.50	11.59	0.83
ANNUAL	48.4			48.24	72.22 (1898)	30.69 (1965)

TABLE 1-10

MEAN MONTHLY SNOWFALL
(Depth in Inches)

	PROVIDENCE, RHODE ISLAND 40 Years of Records	GROTON, CONNECTICUT 1955-1976	KINGSTON, RHODE ISLAND 1890-1976
Month	Mean	Mean	Mean
January	10.2	6.8	8.6
February	10.5	6.6	9.2
March	7.8	5.3	6.9
April	0.5	0.3	0.8
May	0	0.0	Trace
June	0	Trace	0.0
July	0	0.0	0.0
August	0	Trace	0.0
September	0	0.0	0.0
October	Trace	Trace	Trace
November	1.3	0.4	1.0
December	7.8	5.8	6.4
ANNUAL	37.5	25.2	32.9

TABLE 1-11

WATER EQUIVALENT OF SNOW COVER
(Inches)

Blackstone River Basin
1957-1977

Date	Minimum	Mean	Maximum
1 February	0.0	1.6	3.9
15 February	0.0	2.1	5.2
1 March	0.0	2.3	6.0
15 March	0.0	1.7	5.0
1 April	0.0	0.5	3.3
15 April	0.0	0.0	0.7

TABLE 1-11

WATER EQUIVALENTS OF SNOW COVER
(Inches)

Blackstone River Basin
1957-1977

DATE	MINIMUM	MEAN	MAXIMUM
1 February	0.0	1.6	3.9
15 February	0.0	2.1	5.2
1 March	0.0	2.3	6.0
15 March	0.0	1.7	5.0
1 April	0.0	0.5	3.3
15 April	0.0	0.0	0.7

Six recent flood producing storms in the southeastern New England region occurred in March 1936, July 1938, September 1954, August 1955, October 1962 and March 1968. Hurricane "Diane" of August 1955 produced floods throughout much of southern New England. The accompanying rains fell on grounds previously saturated by rainfall from hurricane "Connie" which occurred a week earlier. The March 1968 storm was of a lesser magnitude than the 1955 but occurred in the spring when antecedent conditions due to snow melt were high. This produced record flows in many southeastern New England streams.

TOPOGRAPHY

The Woonasquatucket River Basin lies principally within the Seaboard Lowland section of the New England Physiographic Province. The western third of the basin is in the New England Upland Section. The basin has an irregular topographic surface gently sloping easterly toward Narragansett Bay from a maximum elevation of approximately 627 feet above mean sea level, occurring at Absalona Hill in Gloucester. Its topography is characterized by many low hills of unconsolidated glacial materials with rock commonly providing local relief especially in the area most northwest of greater Providence.

The two river valleys forming the basin are well defined in spite of considerable urbanization around Providence. The Woonasquatucket River, being the principal and larger river, drains the irregular topography in the northwestern portion of the basin. In areas where drainage has been partially blocked, small to large swamps have developed. Modifications of landforms by cuts and fills are generally minimal in the central and northern portion of the basins, but increase in frequency and extent in the southern section, especially in the highly urbanized areas of Providence and Pawtucket.

The topography of the basin has had an extensive influence on the history and development process as most of the urbanization has taken place in the river valleys and in the nearly level areas in Providence, adjacent to Narragansett Bay. Four U.S. Geological Survey Maps (1970 photo revisions) compiled at a scale of 1:24,000 (Plate 1-5) with 10-foot contour intervals delineate the topographical location of the Woonasquatucket Basin.

Much of the Pawcatuck River Basin is a lowland sloping southward from a narrow, irregular divide which is generally less than 500 feet NGVD. It reaches an elevation of 600 feet NGVD at only a few points. The major part of the basin is below an elevation of 200 feet. Low, rounded hills rise above very wide valleys where glacial deposits furnish the major relief. The surface of the whole basin has been modified by glaciation. The valleys are deeply filled with glacial outwash material. Terraces, kames, and kettle-holes occur on these valley plains. The bedrock hills have a thin veneer of glacial till. In a few areas, drumlins - elliptical hills composed entirely of till - are found. The divide on the south side

of the basin is a recessional moraine which extends along the shore from Watch Hill to Narragansett pier. Drainage is very poorly developed throughout the region. Streams wind across the wide, flat, swampy valley floors between the hummocky kames and kettle-hole ponds. Some of the swamps are extensive, covering areas up to several square miles. Except in the town of Westerly, modification of landforms by cuts and fills are minimal throughout the basin apparently due to the rural character of the basin. Most urbanization of the basin has taken place in the southwest corner along the Pawcatuck River. The topography of the basin is shwon on 13 U.S. Geological Survey Maps (1970 Photo-revisions) compiled at a scale of 1:24,000 with 10-foot contour intervals.

Narragansett Bay and its associated coastal streams are in the Seaboard Lowland section of the New England Physiographic Province. The Seaboard Lowland section is characterized as an irregular surface with maximum elevations less than 500 feet. The topography of the Narragansett Bay Local Drainage Area is governed by geologic structure. Heavy outwash deposits from east Greenwich to Quonset provide a low flat plain at the lower elevations in the drainage area. Fluvio-glacial sands east of Nyatt Point present a slightly undulating terrace. Projections of the old sedimentary rock structure stand out as moderately high islands. The drainage area reaches a maximum elevation of about 300 feet; this occurs where crystalline old land nears the bay, notably west of Greenwich Bay. The area under study is topographically delineated on U.S. Geological Survey Maps (1970 photo revisions) compiled at a scale of 1:24,000 with 10-foot contour intervals.

WATER SUPPLY

PAWCATUCK RIVER BASIN

The Pawcatuck River Basin has abundant ground water resources, however, only a fraction of the area's supplies have been tapped. The area's 15 small water supply systems used supplied 7 mgd to local communities in 1970. The two largest systems, the Wakefield Water Company and the Westerly Water Department, supply out-of-basin and, in Westerly's case, out-of-state water needs. Facing only moderate development pressures and low estimated future demands, it is clear that the planning area will be able to supply its own mid-to-long range needs. To fulfill that estimation, however, municipalities will have to establish strict land use regulations. In some cases this would involve purchasing and managing existing, privately-owned water supply systems to provide better interim coordination and planning. A summary of the water supply sources for the Pawcatuck River Basin is shown on Table 1-12.

WOONASQUATUCKET RIVER BASIN

The ground water resources of the Woonasquatucket River Basin have been and are currently being evaluated by the U.S. Geological Survey in cooperation with the Rhode Island Water Resources Board. The basin's

TABLE 1-12

SUMMARY OF WATER SUPPLY
PAWCATUCK RIVER BASIN

Municipality	Source (Existing System (1978))	Safe Yield mgd
RHODE ISLAND		
Charlestown	Wells	0
Exeter	Private Wells	0
Hopkinton	Private Wells	0
Richmond	Wells	0
S. Kingstown	Wells	1.86
Westerly	Wells	5.90
CONNECTICUT		
Stonington	Westerly	6.00
	Reservoir & Wells	2.00
	Wells	0.03
N. Stonington	Wells	0.35
Voluntown	Private Wells	--

major ground water reservoirs lie primarily in the stream valleys. They are generally less than 200 feet thick and composed of irregularly shaped deposits of stratified glacial sand and gravel. Only the thickest parts of the aquifer can withstand pumpage sufficient for municipal supply. Generally the aquifer thickness and permeability varies markedly over small distances, thereby requiring subsurface exploration for location and development of a municipal ground water supply. The ground water is generally of good chemical quality, suitable for domestic and most industrial uses.

The principle areas within the Woonasquatucket River Basin from which ground water can be withdrawn is a blanket of stratified drift more than 60 feet thick, lying to the south of the Woonasquatucket Reservoir. A realistic sustained yield from this reservoir is 1 mgd. A second area lies in the Providence area where the projected sustained yield from this location is 4 mgd. Another area is located along the Moshassuck River Valley where ground water recharge results from direct infiltration from precipitation, subsurface inflow from till and bedrock near the aquifer, and potential infiltration from the Moshassuck River itself. Its estimated safe yield is 5.5 mgd; however, it should be noted that continual pumping and export of this amount of water from the aquifer area could cause the Moshassuck River to dry up during the summer months and in periods of drought.

The principle surface water supplier for communities within the Woonasquatucket River basin is the Providence Water Board. Four of the communities namely, Providence, portions of North Providence, Cranston and eastern sections of Johnston, rely on the board for their water supply needs. Even though two small areas within Smithfield are serviced by the East Smithfield Water District and the Greenville Water District, these districts together with the remaining sections of the town also rely on the Providence system for a dependable yield.

Western section of Pawtucket and Central Falls, and eastern areas of North Providence are serviced by the Pawtucket water works system. This system obtains its supply from a series of six reservoirs (Diamond Hill and Arnold Mills Reservoirs, Rawson, Howard, Robin Hollow and Happly Hollow Ponds) in the Abbott Run watershed, a tributary of the Blackstone River, and four gravel packed wells. The town of Lincoln has its own water system, using wells along the Blackstone River in conjunction with the Pawtucket system. The remaining watershed communities of North Smithfield and Gloucester, as well, as the western section of Johnston obtain their water from private wells.

Based on 1975 estimates the Providence Water System supplied an average of 62.4 mgd, of which the city of Providence with Cranston, Johnston and North Providence used 47.7 mgd, Smithfield and North Providence used 1.77 mgd. The entire Providence Water Supply was obtained from the Scituate Reservoir complex which has a safe yield of 72 mgd, and is located in the adjoining Pawtuxet River basin. The projected average

day water supply demand on the Providence system in 1995 is 85.5 mgd, which exceeds the safe yield by 13.5 mgd. One remedy to this situation is the expansion of the Providence system by means of developing Big River Reservoir system in the Pawtuxet River basin, and other basin transfers as indicated by the Water Resources Board of Rhode Island.

The community of Lincoln, which has its own ground water supply system used an average of 1.93 mgd in 1975, approximately one-third of this was for industrial use. The estimated 1995 demand is 2.59 mgd while the capacity of the system is 5.5 mgd.

NARRAGANSETT BAY LOCAL DRAINAGE

Ground water resources in the Narragansett Bay area are irregularly distributed and scarce. Salt water intrusion, thin aquifers, and shallow bedrock, all contribute to this condition. The best ground water reservoir is a buried channel in the Potowomut River Valley, where bedrock lies more than 100 feet below land surface. Two other areas, where large supplies of ground water can be obtained frcm thick beds of sand and gravel, are in the valley of the west tributary of the Pettaquamscutt River and west of Belleville Pond. This principal reservoir can sustain 8 mgd. A second and third ground water source in this area are estimated to be capable of yielding as much as 5 mgd and 3.6 mgd, respectively.

Sand and gravel deposits in the Barrington-Warren area constitute a ground water reservoir that is already developed to its full potential. Glacial deposits in the Palmer River valley in Massachusetts seem to be only slightly favorable for exploration for ground water sources capable of meeting industrial and public supply needs. Sand and gravel deposits tapped by Dighton and Swansea in the Cole River and Heath Brook basins are thin and, therefore, have little available drawdown and aquifer storage.

The Eastern Bay area includes southeastern Rhode Island and islands in Narragansett Bay. The area is practically devoid of deposits favorable for the development of ground water resources capable of sustaining public water supplies. However, as in most areas of New England, the bedrock aquifer if capable of yielding water to drilled wells in quantities sufficient for domestic supplies. Wells in bedrock near surface bodies of salty and brackish water may yield brackish water.

Surface water supplies for the Narragansett Bay area include reservoirs supplying the communities of Bristol, Jamestown, Middletown, Newport, Portsmouth, Tiverton, Warren and Warwick. Proposed additional sources of supply are the Big Reservoir and the Cole River Reservoir.

The two major water supply systems now serving the Narragansett Bay area also supply water to other basins within Rhode Island. The Providence Water Supply Board's Scituate Reservoir complex has an estimated available safe yield of 72.0 mgd. The sources of supply of the Kent County Water Authority are wells located in Coventry and East Greenwich which yield 9.8 mgd.

WATER QUALITY

Water quality standards for classification of waters as shown on plate 1-7 are as follows: Class A (Class SA, tidal) waters are uniformly excellent in character and suitable for water supply. Class B (Class SB, tidal) waters are suitable for bathing and other recreational uses, industrial and agricultural use and are excellent fish and wildlife habitats. Class C (Class SC, tidal) waters are suitable for fish and wildlife habitat, recreational boating and industrial use. Class B and C waters must also be substantially free of pollutants that affect the physical or chemical composition of the bottom, the composition of bottom fauna, or interfere with the propagation of fish. Class D (Class SD, tidal) waters are suitable for navigation, power, some industrial uses, migration of fish and have good aesthetic value.

The following paragraphs discuss the water quality of the Woonasquatucket Basin, the Pawcatuck Basin and the Narragansett Bay Local Drainage Area.

PAWCATUCK RIVER BASIN

The headwaters and tributaries of the Pawcatuck River are generally Class A or B, according to Rhode Island and Connecticut water quality standards. The mainstem of the Pawcatuck is classified as B and C waters, but certain reaches are not in compliance with their classification. Those reaches not in compliance with Class B standards are: White Horn Brook, Wood River just above its confluence with the Canonchet Brook, Caroline Mill Pond on the Pawcatuck, and the Pawcatuck River between Ashaway and White Rock. All other non-tidal waters in the Pawcatuck River Basin are Class C or higher and are suitable for fish and wildlife habitat, recreational boating and industrial water supply. Little Narragansett Bay does not meet the standards of its SA and SB classifications due to upstream discharges. These discharges include Westerly's primary treatment plant and industrial and combined sewer discharges in Pawcatuck, Connecticut.

The major sources of pollution along the river are industrial discharges, municipal treatment discharges and private sanitary discharges. A major industrial discharger to the Pawcatuck River is the Kenyon Piece Dye Works which has a permit for best practical treatment that will result in at least Class C waters below the discharge. The Westerly wastewater treatment facility, with a discharge of 1.3 mgd, is the largest pollution source on the Pawcatuck River and the only municipal treatment plant.

While a basin plan has not yet been prepared as required by the Federal Water Pollution Control Act Amendments of 1972, proposals have been developed by the various town consultants, industries, the Rhode Island Department of Health and the Connecticut Department of Environmental Protection.

WOONASQUATUCKET RIVER BASIN

The existing water quality in the Woonasquatucket River Basin ranges from Class B to Class C. The upper portion of the basin from Waterman Reservoir to Georgiaville Pond is a series of reservoirs and old mill ponds which are predominantly Class B. Neither the Stillwater Reservoir nor the Woonasquatucket Reservoir, both located in the upper basin, are in compliance with the Class B standard due to two small wastewater treatment facilities discharging effluent just upstream of Stillwater Reservoir. They should be brought into compliance with the completion of the Smithfield sewerage system.

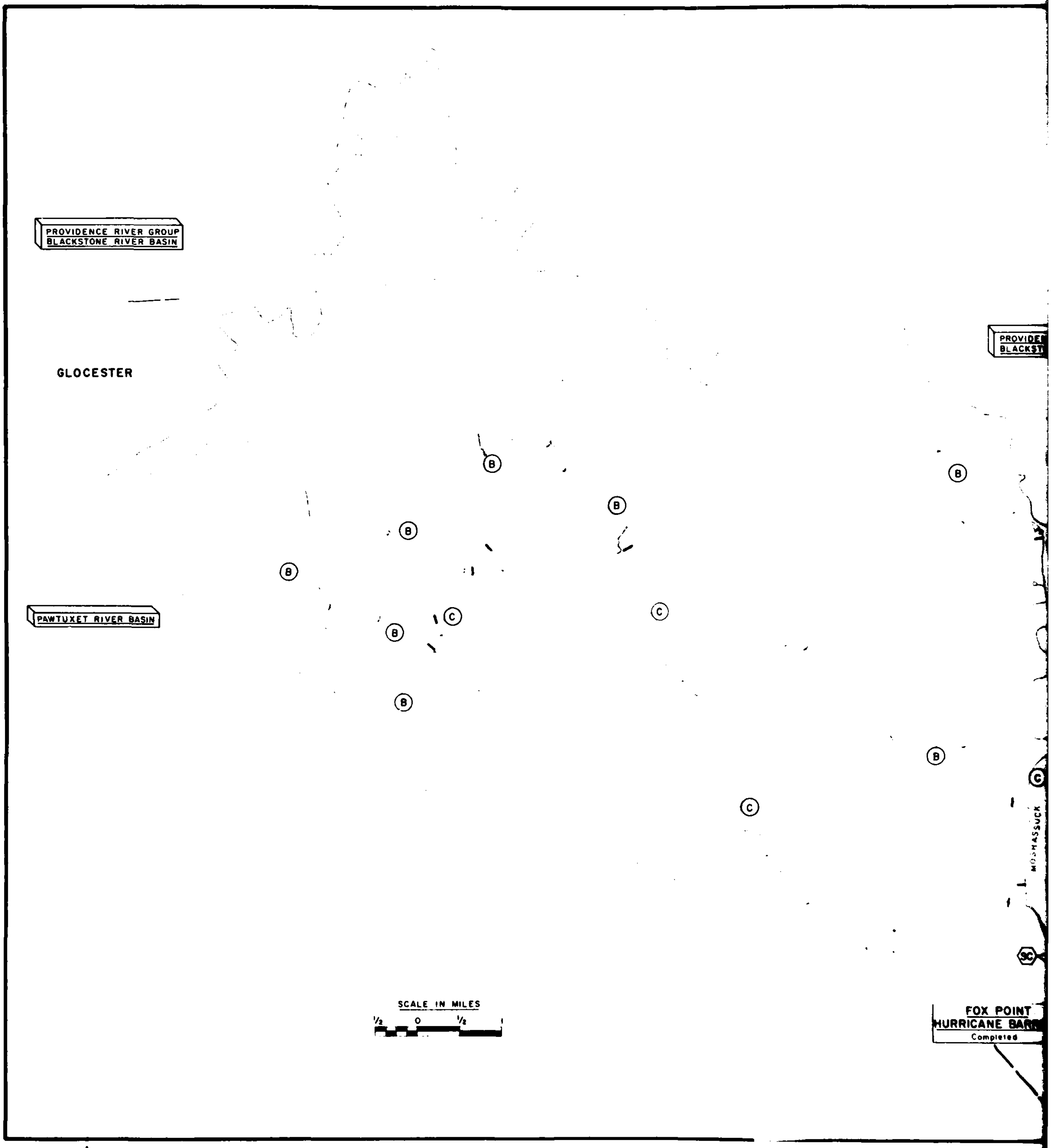
The lower basin from Georgiaville Pond to the Providence River is entirely Class C. The entire city of Providence is served by a municipal sewerage system which, due to its being a combined system, is not capable of providing adequate treatment of the sewage during periods of heavy rainfall. Bypass of the treatment plant at these time results in high coliform counts in Narragansett Bay. The Rhode Island Department of Health has recognized the need for separation of this combined sewer system and consequently assigned this project the highest ultimate priority points in its list for Federal and State construction grants for sewerage works.

The Woonasquatucket is tidal from Fox Point Barrier up to Eagle Street and, therefore, is affected by water quality of the Providence River during flood tide. This portion of the river has been assigned a Class SC standard. The attainment of Class SB waters will depend on an effective and costly program to abate pollution emanating from the Providence combined sewer and storm runoff system.

The Moshassuck River is Class B from its origin to Blechery Pond in Lincoln. Due to industrial and municipal discharges, the river is Class C from Blechery Pond to its confluence with the Woonasquatucket River. The Moshassuck's major tributary, the West River is Class B.

NARRAGANSETT BAY LOCAL DRAINAGE

The upper portion of the basin is intensely developed and is quite prone to problems associated with the transport of oil. This is especially true in the Seekonk-Providence River area, near Fall River, Massachusetts and the Tiverton, Rhode Island area. Thermal stratification exists from February through July. However, Narragansett Bay is basically a well-mixed estuary due to four major mechanisms: tidal movements, surface and bottom drifts resulting from spatial density differences due to fresh water interflows, wind-driven transient circulation, and turbulent motion. This situation helps explain why several primary outfalls are creating no noticeable problems in the areas of their ocean outfalls. Discharges in the upper portions of the bay, principally in the


PROVIDENCE RIVER GROUP
BLACKSTONE RIVER BASIN
GLOCESTER
PAWTUXET RIVER BASIN
B
C
SC
MOSHASSUCK
SCALE IN MILES
½ 0 ½ 1
FOX POINT
Completed

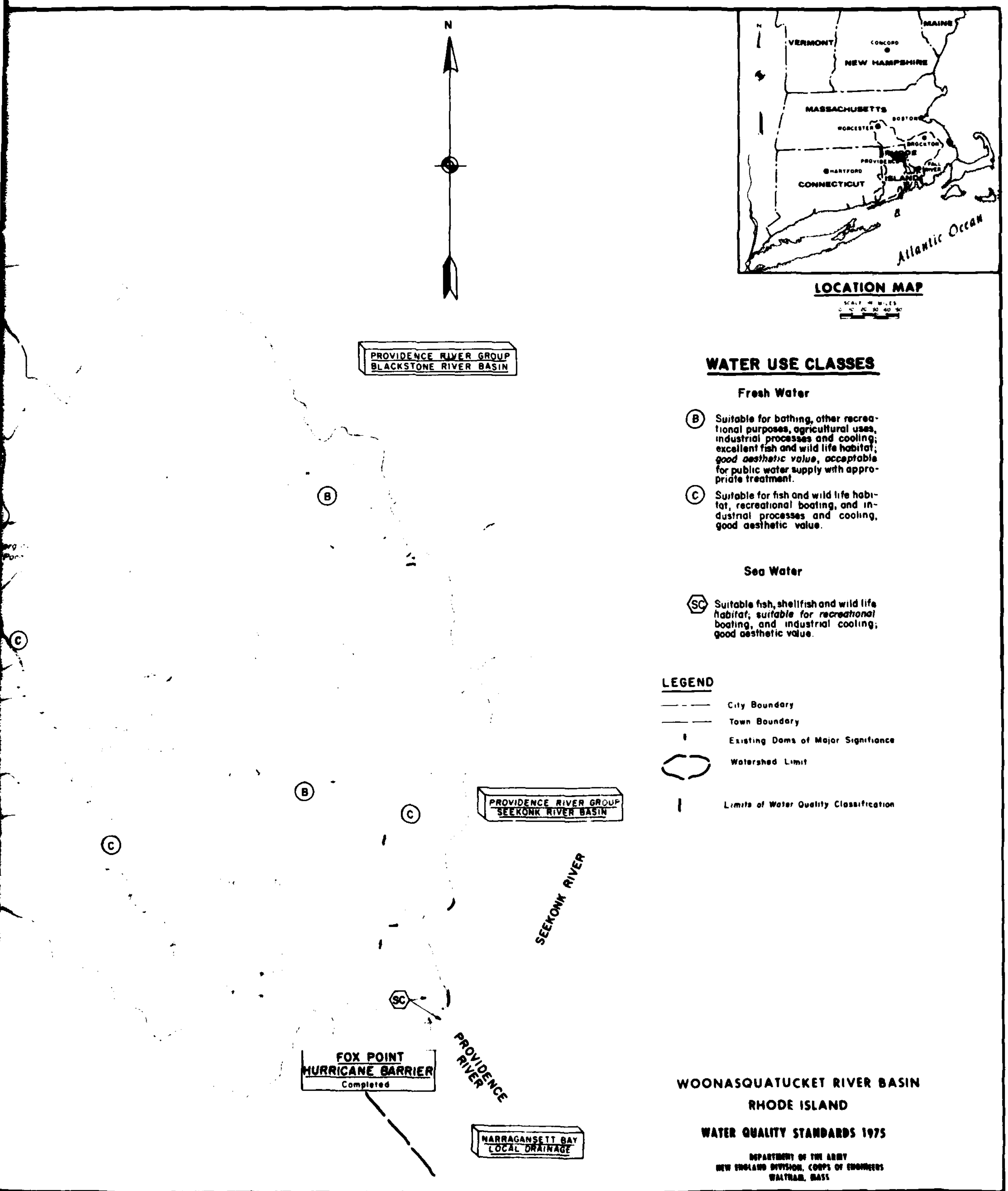

N
VERMONT
CONCORD
NEW HAMPSHIRE
MAINE
MASSACHUSETTS
BOSTON
WORCESTER
BROCKTON
PROVIDENCE
FALL RIVER
HARTFORD
CONNECTICUT
RHODE ISLAND
Atlantic Ocean
LOCATION MAP
PROVIDENCE RIVER GROUP
BLACKSTONE RIVER BASIN
WATER USE CLASSES
Fresh Water
B Suitable for bathing, other recreational purposes, agricultural uses, industrial processes and cooling; excellent fish and wild life habitat; good aesthetic value, acceptable for public water supply with appropriate treatment.
C Suitable for fish and wild life habitat, recreational boating, and industrial processes and cooling, good aesthetic value.
Sea Water
SC Suitable fish, shellfish and wild life habitat; suitable for recreational boating, and industrial cooling; good aesthetic value.
LEGEND
City Boundary
Town Boundary
Existing Dams of Major Significance
Watershed Limit
Limits of Water Quality Classification
B
C
B
C
C
SC
PROVIDENCE RIVER GROUP
SEEKONK RIVER BASIN
SEEKONK RIVER
PROVIDENCE RIVER
FOX POINT
HURRICANE BARRIER
Completed
NARRAGANSETT BAY
LOCAL DRAINAGE
WOONASQUATUCKET RIVER BASIN
RHODE ISLAND
WATER QUALITY STANDARDS 1975
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS

PLATE 1-7

Seekonk-Providence system, may not be able to take full advantage of these mixing phenomena, since salinity stratification is most intense in the upper bay due to fresh water inflows.

Several portions of streams within the study area are below proposed water quality standards at this time. The Seekonk-Providence Rivers area is the most severely degraded within Narragansett Bay. The wastewater treatment facilities in the Blackstone Valley Sewer District, East Providence, and Providence, discharge significant waste daily into the two tidal rivers. But it is the combined sewers of Providence, Pawtucket and Central Falls which create the major water quality problems in the Providence River and upper Narragansett Bay area.

The Fall River - Tiverton area is the other major problem area in Narragansett Bay. Water quality in Mount Hope Bay suffers from 14 combined sewer overflows and also from the primary effluent of the hydraulically overloaded Fall River Wastewater Treatment Facility. The problem is compounded by a large industrial flow to the plant which could cause problems if biological secondary treatment is added. Oil is also a major problem in the area. Terminals in Fall River and Tiverton experience minor spills occasionally. The combined sewer system of Fall River carries oils that leak onto the streets and are washed into the sewers during rain storms.

New England Power's Brayton Point power plant creates a recognized thermal problem in the Mount Hope Bay area. Several fish kills have been observed and the elevated temperatures in the Lee River coupled with the nutrients entering the bay from the Taunton River and the Fall River facility have encouraged luxurious growths of marine algae.

The vast majority of waters are meeting proposed standards of Class SA and SB quality waters. The Seekonk and Providence Rivers, Jamestown Harbor, portions of Mt. Hope Bay particularly around Fall River, Newport Harbor, waters surrounding the U.S. Naval Reservation at Quonset Point, Apponaug Cove, and the Barrington River at Barrington, are all Class SC.

PROBLEMS & NEEDS

PAWCATUCK RIVER BASIN

Existing Conditions - Although the Pawcatuck planning area has experienced several relatively rare flood events, the damage associated with these floods has been minimal in the nontidal portion of the basin. Flat terrain, numerous ponds and streams, extensive wetlands and minimum development have combined to limit the extent of inland flooding in the Pawcatuck area. The flood of record occured in March 1968. Other major floods were in February 1886, November 1927 and September 1932.

Numerous ponds and an extensive network of wetland areas plus a significant amount of undeveloped forested land have served to modify high flood flows and keep flood damages at minimal levels. A total of some 3,700 acres of lakes and ponds are scattered throughout the area. Nearly one half of the total water surface area is concentrated in the southerly sections or downstream areas of the basin. The largest is Worden Pond in South Kingstown where the Pawcatuck River originates; the second in size is Watchaug Pond in Charlestown. During flooding periods these ponds and lakes act as detention areas where excess runoff can be stored thus reducing the amount of floodwaters entering the extreme downstream regions.

In addition to these open water bodies, many wetland areas are scattered throughout the basin and they also provide additional natural valley storage areas where excess runoff can be temporarily stored prior to release into downstream areas. Inland wetland areas total over 30,000 acres or about 47 square miles. This constitutes over 15 percent of the total land area in the Pawcatuck River Basin. The largest individual wetland area in the basin is the Great Swamp located within the Great Swamp Wildlife Reservation in South Kingstown. Table 1-13 lists Federal and State owned wetlands.

Wetlands frequently play an important role in natural flood protection. The preservation of wetlands upstream from developed areas provides overflow areas where floodwaters will do little damage. The wetlands reduce the severity of floods by allowing floodwaters to spread out, by slowing their flow and by temporarily storing water. Their action reduces the flood peak along the main stream although it may lengthen duration of the flood.

In New England, experience with runoff associated with most major storms has shown that natural or man-made storage capable of storing six inches of runoff from the upstream drainage area will usually be effective in minimizing downstream damage. Using this six-inch runoff criterion and assuming that the average depth of storage in the wetlands is five feet, the storage capacity of the wetlands can be estimated. Plate 1-8 shows the potential flood water detention capacity of the various sub-basins.

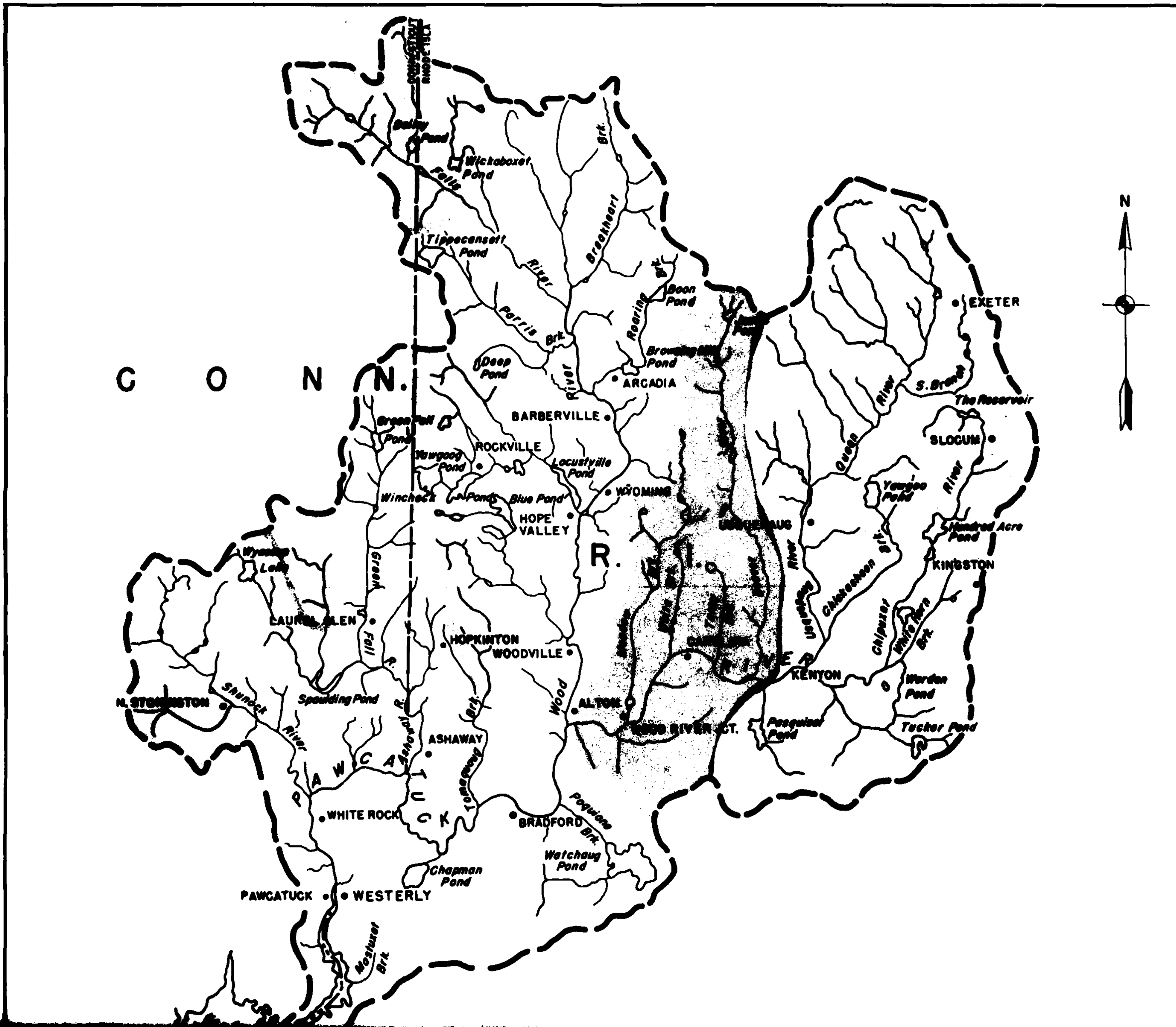
As shown in the diagram most of the estimated runoff in the northeastern portion of the basin is stored in the various wetlands, particularly the Great Swamp and Indian Cedar Swamp. At the confluence with the Wood River, nearly 90 percent of the total flood flow is contributed by the Wood River sub-basin. The last two swamps on the main stem of the Pawcatuck River, Watchaug Pond Swamp, and Chapman Pond Swamp have the capacity to store a large portion of the excess runoff in addition to the runoff from their respective drainage areas. The runoff not stored by these two swamps contributes less than 30 percent to the total runoff at the mouth of the river. The balance is mainly due to runoff from the lower portions of the Ashaway and Shunock River sub-basins, Westerly, White Rock and Stillmanville in Rhode Island and Pawcatuck and Clarks Village in Connecticut.

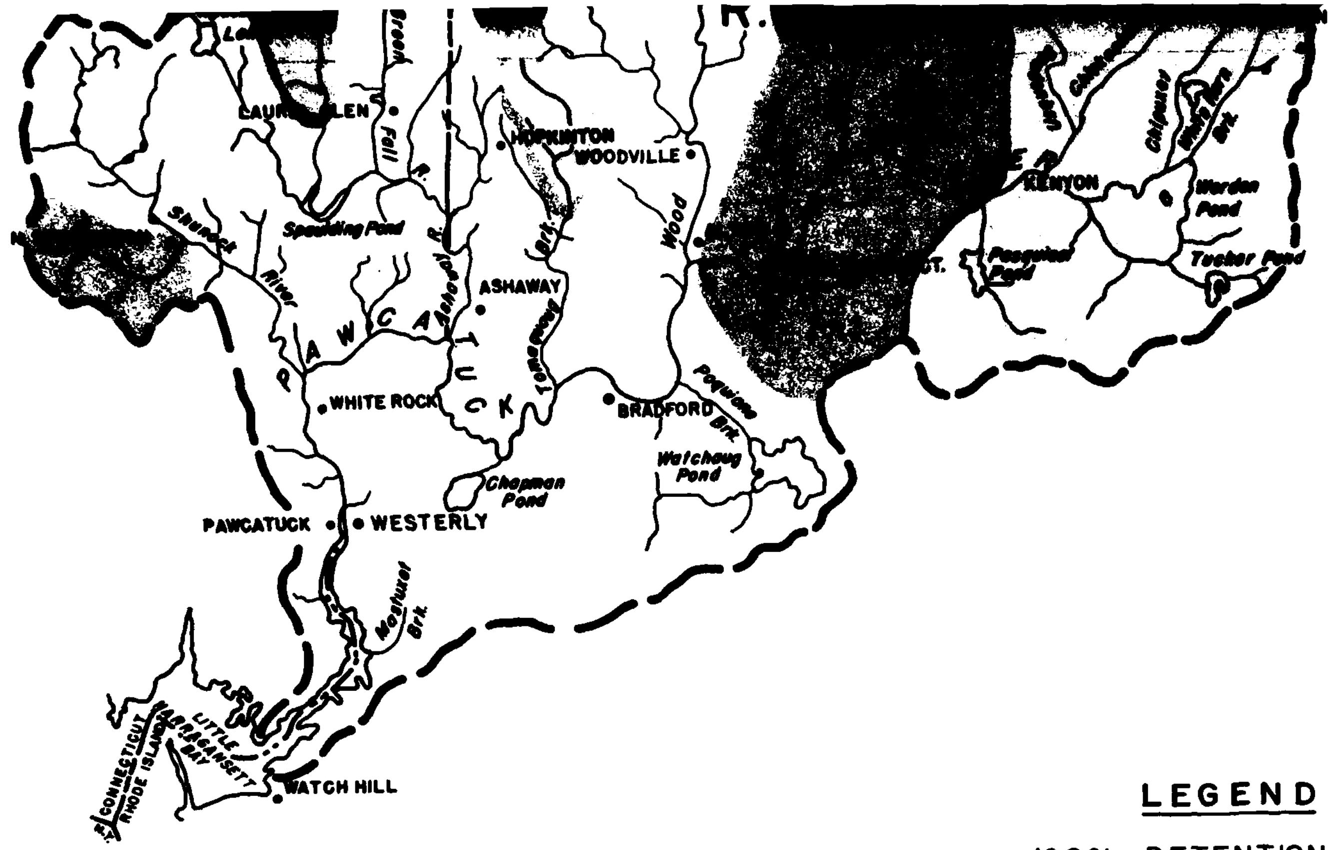
TABLE 1-13

Wildlife Management & Conservation Areas
Owned By RI Dept. of Natural Resources
Pawcatuck River Basin

Area	Location	Acreage	Wetland Acreage
Arcadia Mgt. Area	Exeter, Richmond West Greenwich	7,345	296
Arcadia St. Park	Richmond, Exeter	55	-
Assekonk Swamp Hunting Area	North Stonington	697	302
Barber Pond Public Fishing Area	South Kingstown	28	-
Beach Pond St. Park	Exeter	3,436	27
Burlingame Mgt. Area	Charlestown	647	-
Burlingame St. Park	Charlestown	2,375	860
Carolina Mgt. Area	Richmond	1,569	38
Dawley Memorial St. Park	Richmond	200	-
Deep Pond Fishing Area	Charlestown	232	-
Ell Pond Mgt. Area	Hopkinton	115	57
Flat River Public Fishing Area	Exeter	134	-
Great Swamp Fight Historical Site	South Kingstown	41	34
Great Swamp Mgt. Area	Richmond, South Kingstown	2,275	2,265
Indian Burial Ground	Charlestown	21	-
Indian Cedar Swamp Mgt. Area	Charlestown	850	617
Maiello Mgt. Area	Exeter	91	-
Moscow Pond Public Fishing Area	Hopkinton	20	-
Newton Swamp Mgt. Area	Westerly	111	107
Pachaug St. Forest*	Voluntown, North Stonington	3,600	420
Queens Fort	Exeter	64	-
Rockville Mgt. Fishing Area	Hopkinton	132	-
Woody Hill Mgt. Area	Westerly	723	80
Wickaboxet St. Forest (partly within Paw-catuck Basin)		213	17
	TOTALS	24,974	5,120

* Owned by Bureau of Sport Fisheries & Wildlife.


N
CONN.
R. I.
CONNECTICUT
RHODE ISLA
Bailey Pond
Wickaboxet Pond
Falls
Tippecansett Pond
River
Breakheart Brk.
Boon Pond
Roaring Brk.
Parris Brk.
Deep Pond
Browning Pond
ARCADIA
BARBERVILLE
Green Fall Pond
Yawgoog Pond
ROCKVILLE
Locustville Pond
Winchek Pond
Blue Pond
WYOMING
HOPE VALLEY
Wyassup Lake
Green
LAUREL GLEN
Fall
R.
HOPKINTON
WOODVILLE
Wood
N. STONINGTON
Shunock River
Spaulding Pond
Ashaway R.
ALTON
WOOD RIVER JCT.
ASHAWAY
Tomaquag Brk.
P A W C A T U C K
WHITE ROCK
BRADFORD
Poquiong Brk.
Watchaug Pond
Chapman Pond
PAWCATUCK
WESTERLY
Mastuxet Brk.
EXETER
S. Branch
The Reservoir
Queen River
SLOCUM
Yawgoo Pond
River
Hundred Acre Pond
KINGSTON
Usquepaug River
Chickasheen Brk.
Chipuxet
White Horn Brk.
KENYON
Worden Pond
Pasquiset Pond
Tucker Pond



LEGEND

	100% INTO	DETENTION OF RUNOFF THE WETLANDS.
	75% INTO	DETENTION OF RUNOFF THE WETLANDS.
	50% INTO	DETENTION OF RUNOFF THE WETLANDS.

PAWCATUCK RIVER BASIN

FLOOD WATER DETENTION CAPACITY OF WETLAND AREAS

SCALE IN MILES
0 1 2 3

PLATE I-8

2

Several factors are involved in determining the natural effectiveness of inland wetlands in the control of drainage areas. Although surface areas and storage capacity are major features, the location of the wetland within the basin is at least equally important. If wetland areas are not located upstream of existing or probable damage areas, they will have little effect in controlling the flood damage unless the swamp is abnormally large. An extensive wetland, say over 5,000 acres that is located in the upstream reaches of a sluggish tributary would be expected to be capable of storing about 25,000 acre-feet (AF) of runoff. However, if the swamp only had an upstream drainage area of 15 miles it would store only about 5,000 acre feet of runoff from a major flood event, or utilize only 20 percent of the maximum available storage. Whereas a swamp of one half this size, 12,500 AF, but located such that it had an upstream drainage area three times as large would be capable for storing almost the entire runoff from a major flood event. It would also serve to protect any downstream area for a significant length from flood losses. Still another factor involved in determining the natural effectiveness of wetlands is the topography of the basin. Wetlands in remote areas or downstream of potential damage areas cannot function to control flood flows.

Flood plain wetlands are especially valuable due to their dual function as both flood plains and wetlands. During flood conditions, these wetlands act as both natural storage areas and as an increased channel area to pass flows. Due to this enlargement, the velocity and hence rate of flow would slow down and result in a reduced flood stage downstream. The loss of these wetlands would usually cause greater damage than the loss of an equivalent wetland area in the upper reaches of a drainage area.

A large percentage of the wetlands in the Pawcatuck are located in the middle section of the basin. As urban growth moves inland from the coast, there will be some increased pressure for development of wetlands. However, the loss of wetlands should be minimal under existing laws and programs. Presently several laws and programs are used to control loss of wetlands within the States of Rhode Island and Connecticut. The State of Rhode Island Fresh Water Wetlands Act of 1971 established a permit program to control all operations which would alter the biological character of a wetland area. The State of Connecticut Inland Wetlands and Water Courses Act of 1972 is designed to protect and preserve wetlands and water courses from random, unnecessary, undesirable and unregulated uses. The U.S. Army Corps of Engineers Section 404 permit program also closely monitors filling in of wetlands although it ususally works in conjunction with the state laws.

Many of the communities within the basin are currently operating under the emergency provisions of the National Flood Insurance Program administered by the Federal Insurance Administration of the Federal Emergency Management Agency (FEMA). When the flood insurance studies are completed, the municipality must adopt stringent regulations on flood

plain zoning as so indicated in each individual report or become ineligible for any further Federal assistance in the event of future flooding problems. Significant swamps are usually within the limits of the designated "A" zone. Thus future development of many of these areas would be minimal. An additional constraint on developing these wetlands are the generally very high ground water tables or poor soil permeability which would preclude the use of subsurface sewage disposal units. Most of the rural areas still depend on this form of treatment for sewage disposal.

Even with all of the above constraints on developing in wetlands, more acreage is being lost every passing year.

Along the Pawcatuck River there are several areas which have experienced some minor flood damages. These areas are located in the communities of Westerly, Carolina, Richmond and White Rock, Rhode Island and Pawcatuck, Connecticut. Hope Valley and Alton on the Wood River, and the confluence of the Pawcatuck river and Tomaquaug Brook in Rhode Island have also experienced some flooding.

In Hope Valley the problem is downstream of Locustville Pond where the Route 3 bridge opening does not appear to be adequate to pass heavy flows. This would result in a build-up of flood waters causing flows to go over the road. As the village below is fairly low several businesses and the local fire station could be inundated.

In addition, there are a few potential flood damage areas along the tributaries of the Pawcatuck. The first of these is the village of Ashaway (in Hopkinton, Rhode Island) which has been built across the flood plain of the Ashaway River about three-fourths of a mile above the confluence with the Pawcatuck River. A manufacturing company and several residential buildings are subject to flooding in this area. Estimates for damages to this area from the occurrence of a 100-year storm would amount to less than $150,000. A second potential damage area is that of the village of North Stonington, Connecticut, where a small group of homes have located within the 100-year flood plain of the Shunock River. A potential problem could exist at a new residential area just downstream of the center of Westerly. The homes have been built at the existing ground levels some of which are quite susceptible to inundation by either extreme tides or storm surges. However, the developer has built an earth dike protecting the area. The dikes' top width is less than five feet and varies in elevation with a maximum height of less than ten feet. No provisions for a pumping station or adequate control of interior drainage was evident. The dike could provide a false sense of security to the residents living behind it especially if maintenance and upkeep are not performed periodically.

Hurricane and severe storm tidal flooding along the Rhode Island coast, in Little Narragansett Bay and vicinity, has been recorded since 1635. Historical data regarding maximum tidal elevations is very

sparse. A flood frequency relationship has been approximated using high water mark elevation data, historical records for hurricanes and severe storms, and the records of the U.S. Geological Survey gage, located on the Pawcatuck River at Westerly, Rhode Island.

Table 1-14 shows the tide elevations arranged in order of magnitude. This is based on the period 1938 through 1977 (39 years) for which records are available on the Pawcatuck. High river stages in the Westerly-Pawcatuck area are generally caused by a combination of freshwater (river) flow and saltwater (tidal) backwater, but flood damage is primarily due to tidal flooding. Analyses have been made of U.S. Geological Survey recording gage records for the station located at Westerly, Rhode Island. Usually the tidal surge of a storm produces the high watermark, and the river runoff produces a somewhat lower peak about one day later.

The Groton-Stonington-Pawcatuck area has been subjected to tidal flooding from three major hurricanes; severe flooding from those of September 1938 and August 1954 (Carol), and moderate flooding from the hurricane of September 1944.

The flood of record for the Pawcatuck River Basin occurred in March of 1968. In the March 1968 flood, most of the precipitation fell during two separate storms, about four days apart. Precipitation of the first storm was less than that of the second. However, with runoff from melting snow, the earlier storm contributed significantly to antecedent conditions. At Westerly, Rhode Island the peak discharge during the first storm was 2,170 cfs on March 14. Three days later the discharge rate had been reduced to as low as 1720 cfs. On the fourth day, March 18, the second, heavier rainfall began. This precipitation combined with high antecedent conditions and melting snow produced a peak discharge of 4,470 cfs. The abundant swamps and ponds retained much of the initial precipitation but with the second storm occuring immediately after the first, the water levels in these areas were still quite high causing the discharge rate to peak quickly and drop off quickly as shown on Plates 1-9 and 1-14, hydrographs for the March 1968 flood.

The storm associated with the flood of record has a frequency of occurrence of about once in 100 years.

Limited information of flooding as a result of the February 1886 rainfall indicates the occurrence of a "great freshet." Dam failures augmented flood flows and contributed to the damage.

The flood of November 1927 was due to an unusually heavy rainfall. Flood waters on the Pawcatuck River Basin were increased by the failure of a number of upstream dams. Immediately above Westerly, stages were reported as being about three feet higher than the level of ordinary spring freshets, and on the Ashaway River they were 5-1/2 to 6 feet higher. The estimated peak discharge at Westerly in the 1927 flood was

approximately 7,000 cubic feet per second (23 cfs per square mile of usptream drainage area). This estimate was based on the extrapolation of data obtained at the Potter Hill Dam which is located on the Pawcatuck about 0.3 mile above the confluence with the Ashaway River.

The floods of March 1936 and September 1938, which were very severe on many New England rivers, were of minor importance on the Pawcatuck River. The peak flow at Westerly in 1936 is reported as being 3,150 cfs or less than one-half of the peak discharge of 1927. This is principally due to retention areas during times of flood, the basins flat gradient streams, and the lack of intensive urban development in the nontidal portion of the basin.

The damage caused by tidal flooding from the hurricane of September 21, 1938 was the highest ever experienced in the Pawcatuck area. The peak of the wind-induced tidal surge, which arrived approximately 2 hours before the predicted high tide, added 9.5 feet to the predicted normal tide of 0.9 feet ngvd causing flooding to elevation 10.4 feet ngvd at the mouth of the Pawcatuck River. At Pawcatuck, the tide reached an elevationof 11.1 feet ngvd.

Reliable data on experienced hurricane wind velocities in New England began with the September 1938 hurricane. The maximum velocity in New England during this storm was at the Blue Hills Observatory in Milton, Massachusetts, 80 miles northeast of Pawcatuck, where a gust of 186 miles per hour and a sustained 5 minute wind of 121 miles per hour were recorded. At Block Island, Rhode Island, the wind attained a maximum 5 minute sustained velocity of 82 miles per hour from the southeast and maximum gusts of 91 miles per hour were recorded before the anemometer was blown down. Isovel charts[1] and wind direction at one hour intervals were calculated for the Long Island and Block Island Sounds as shown in U.S. Weather Bureau Memorandum HUR 7-75 dated 16 February 1961, entitled, "Detailed Isovel Charts, Long Island Sound, for Hurricanes of August 1952, September 1944, and September 1938." These charts indicated that a maximum wind velocity of 75 miles per hour from the south-southeast occurred concurrently with the peak still water level.

The center or "eye" of the storm entered Connectiut about 15 miles east of New Haven at about 3:30 pm EST on 21 September moving northerly at a rate of 50 to 60 miles per hour. Minimum barometric pressure of 28.66 and 28.90 inches of mercury, respectively, were recorded at Block Island and Providence, Rhode Island. At Hartford, Connecticut, the pressure was 28.04, which is the lowest ever recorded in New England.

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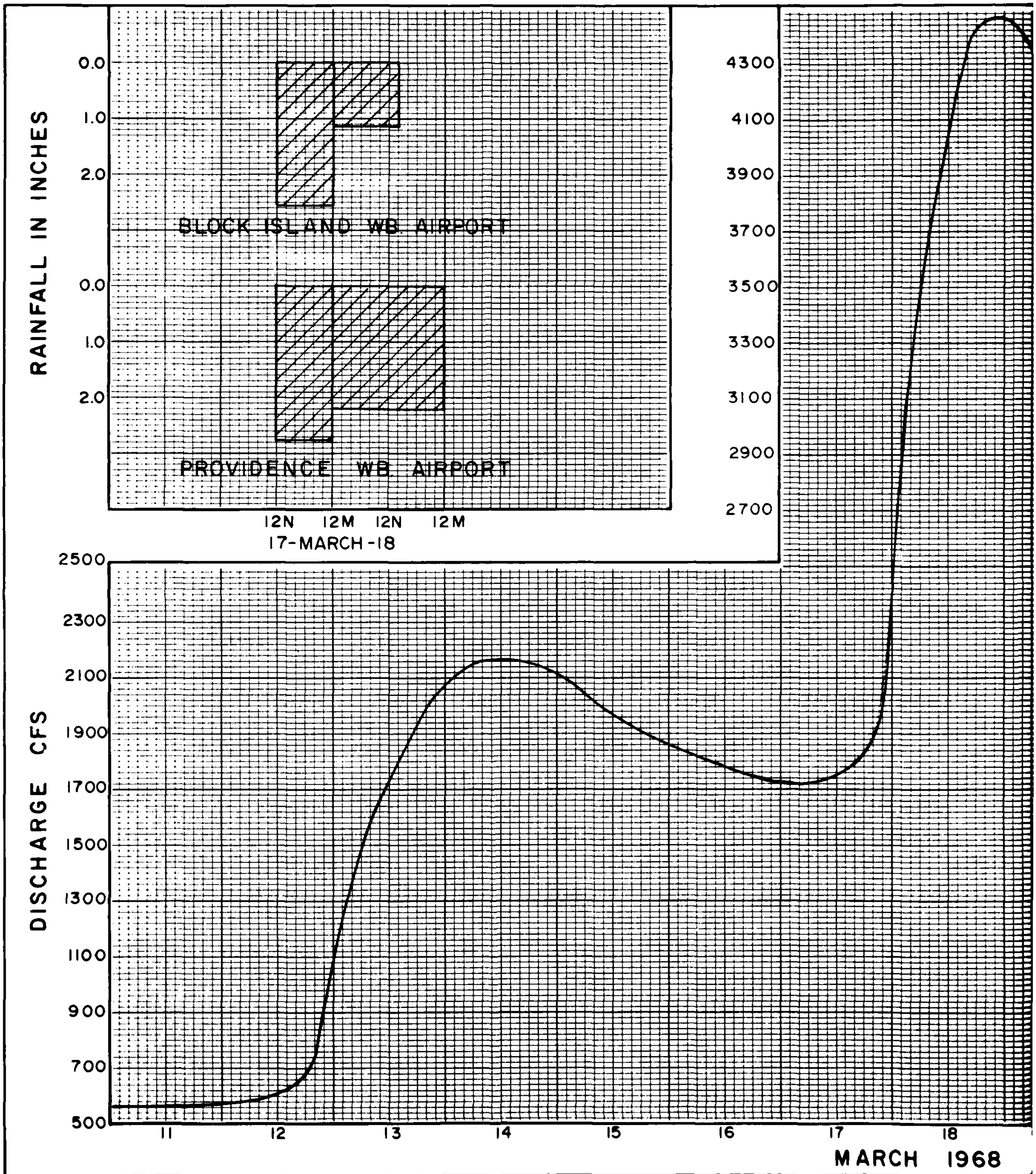
[1]A synoptic chart showing the distribution of wind by means of lines in a given surface connecting points with equal wind speed, also known as isotach or isokinetic charts.

TABLE 1-14

MAXIMUM TIDE LEVELS
HURRICANES AND SEVERE STORMS
MOUTH OF PAWCATUCK RIVER, CONNECTICUT
1938-1977

Hurricane or Storm	Maximum High Water Elevation (ft. NGVD) (1) (From list of annual series data)
Hurricane, 21 Sept. 1938	10.7 (2)
Hurricane "Carol", 31 Aug. 1954	9.9 (2)
Storm, 25 Nov. 1950	7.4 (3)
Hurricane, 14 Sept. 1944	6.9 (3)
Storm, 7 Nov. 1953	6.5 (3)
Hurricane "Donna", 12 Sept. 1960	6.3 (4)
Storm, 12 Nov. 1968	5.9 (3)
Storm, 26 Nov. 1977	5.8 (4)
Storm, 29 Dec. 1966	5.5 (3)
Storm, 12 Nov. 1947	5.4 (3)
Storm, 3 Mar. 1942	5.3 (3)
Storm, 30 Nov. 1963	5.1 (4)
Storm, 19 Feb. 1972	5.0 (4)
Storm, 2 Dec. 1974	5.0 (4)
Storm, 16 Mar. 1956	4.9 (3)
Storm, 16 Feb. 1958	4.8 (4)
Storm, 7 Mar. 1962	4.8 (4)
Storm, 4 Apr. 1973	4.7 (4)
Storm, 6 Mar. 1943	4.7 (3)

(1) Elevations are adjusted to the 1975 level of the sea (based on the rising sea level trend). See Trends and Variability of Yearly Mean Sea Level, 1893-1972, National Ocean Survey, N.O.A.A., Hicks and Crosby.
(2) Based on high water marks.
(3) Based on tidal elevation data at New London, Connecticut and stage related to the mouth of the Pawcatuck River.
(4) Based on record of Corps of Engineers recording tide gage at Stonington, Connecticut and stage related to the mouth of the Pawcatuck River.



RAINFALL IN INCHES
0.0
1.0
2.0
BLOCK ISLAND WB. AIRPORT
0.0
1.0
2.0
PROVIDENCE WB. AIRPORT
12N 12M 12N 12M
17-MARCH-18
4300
4100
3900
3700
3500
3300
3100
2900
2700
2500
2300
2100
1900
1700
1500
1300
1100
900
700
500
DISCHARGE CFS
11 12 13 14 15 16 17 18
MARCH 1968

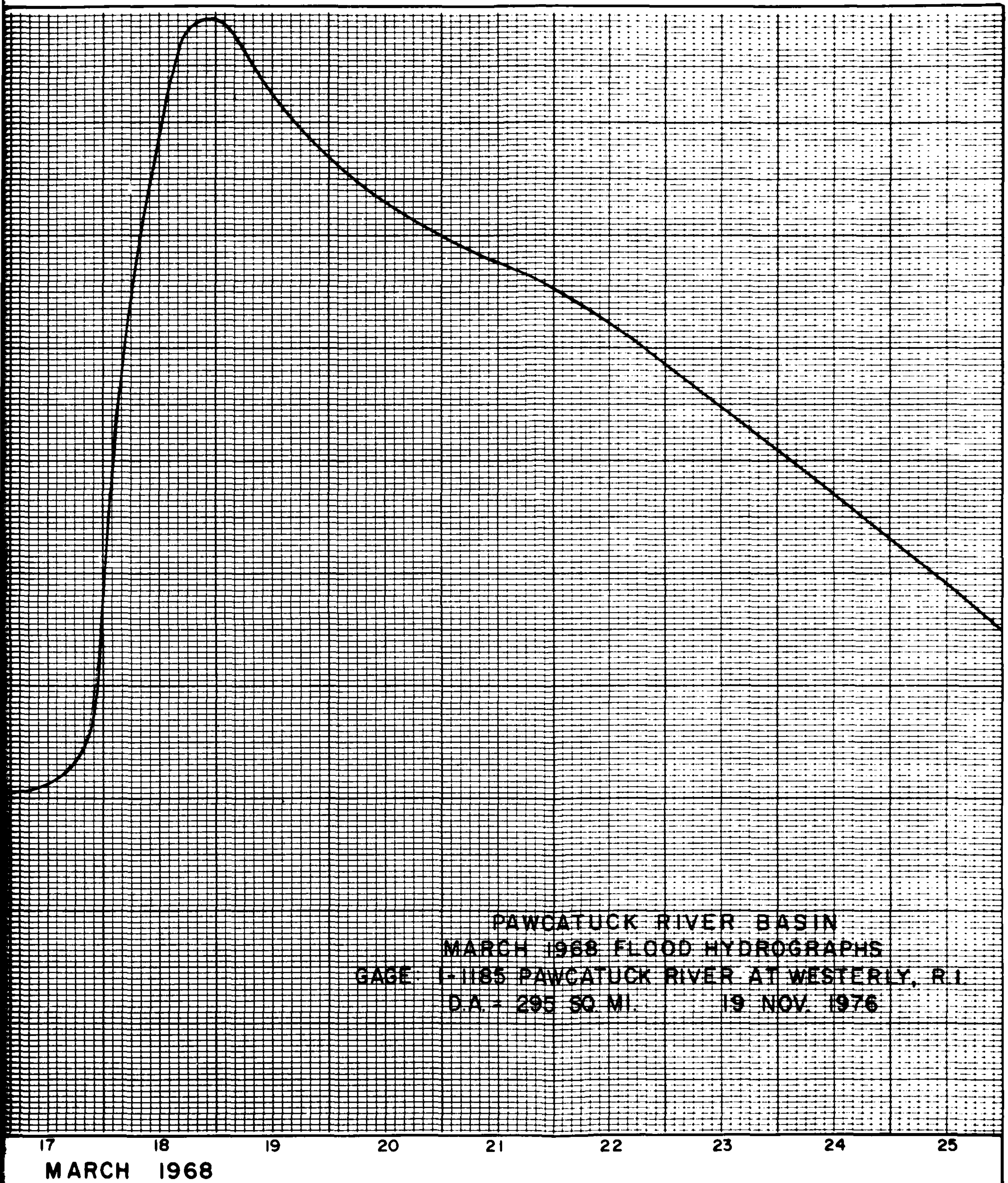
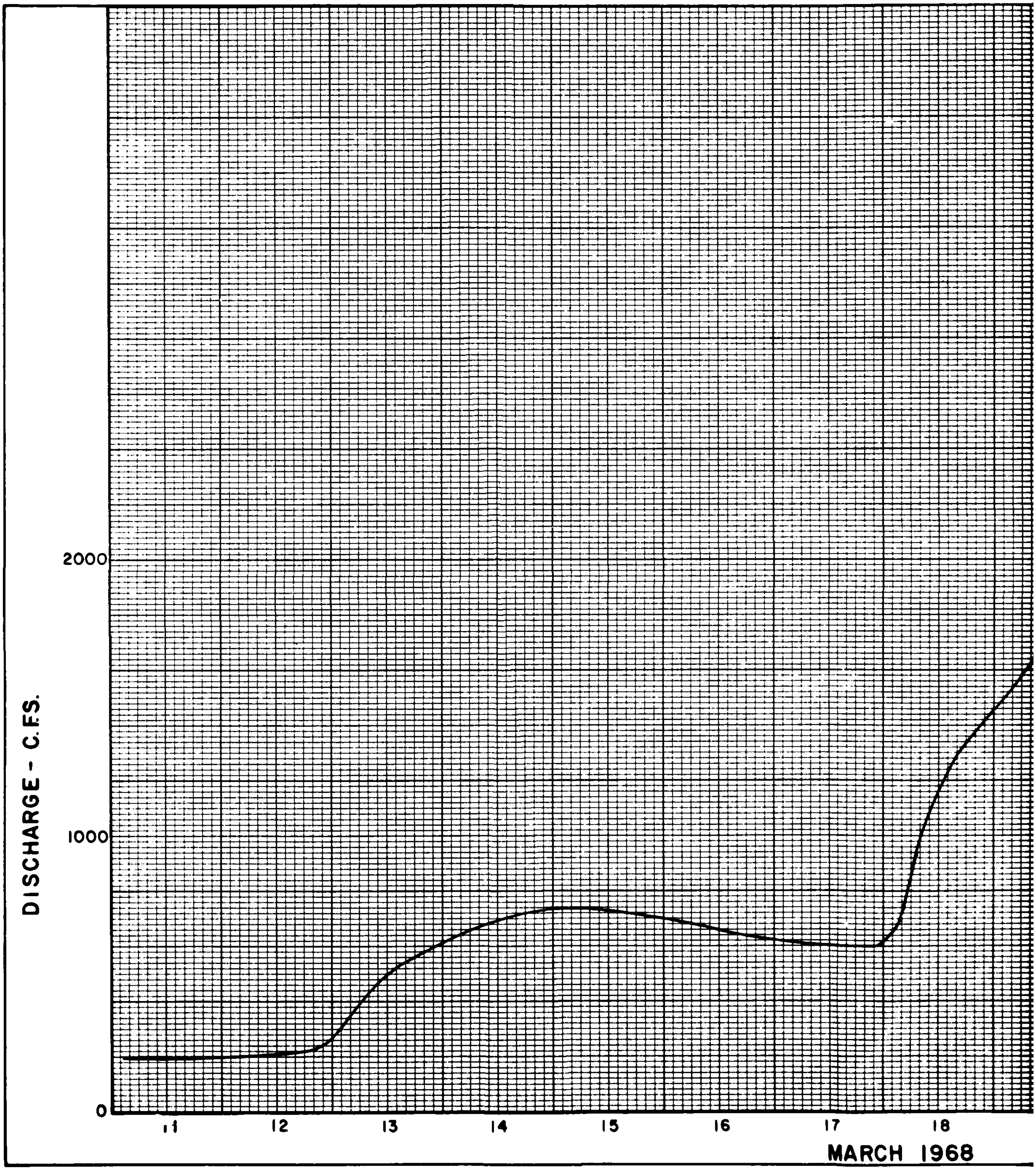
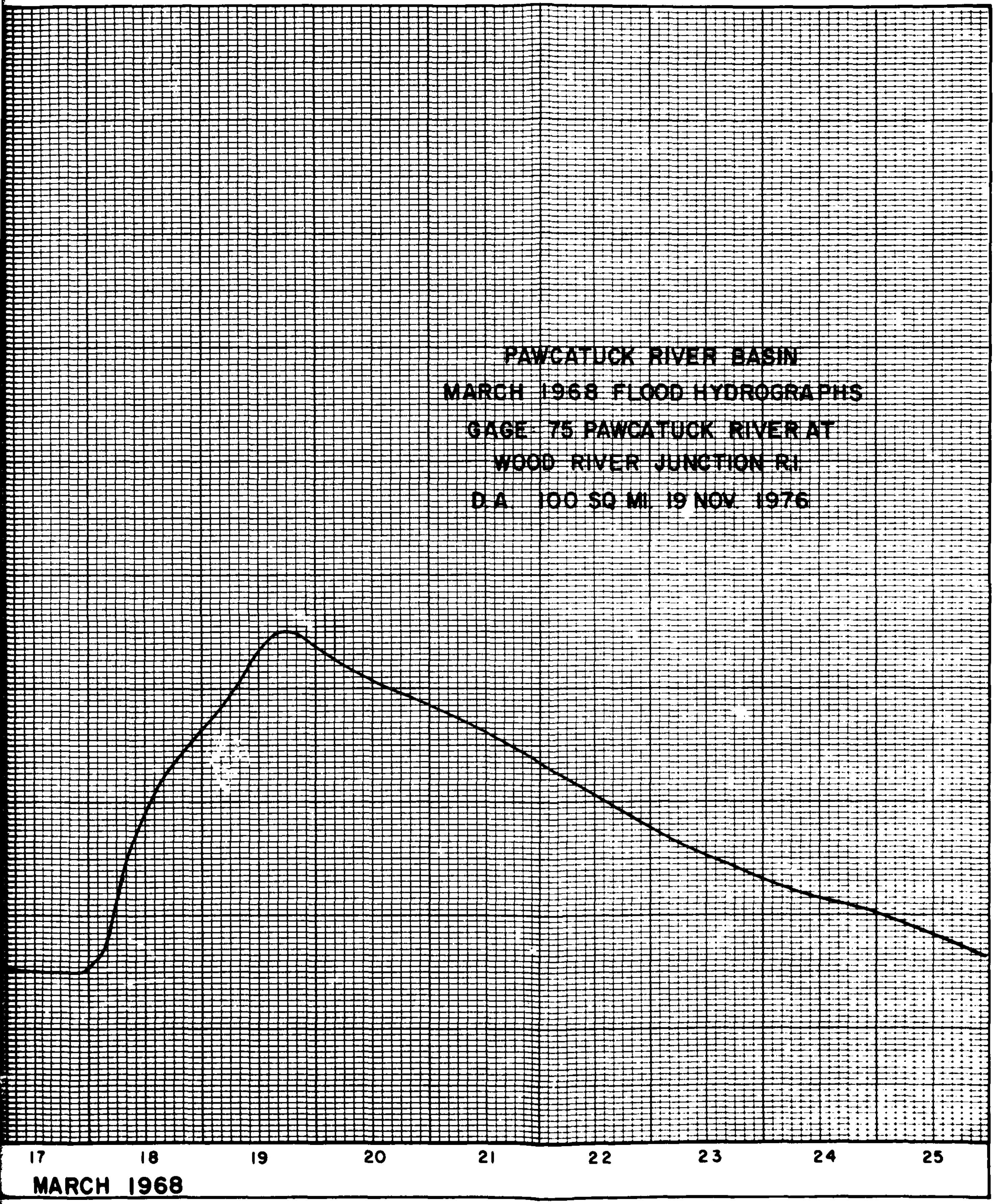

PAWCATUCK RIVER BASIN
MARCH 1968 FLOOD HYDROGRAPHS
GAGE 1-1185 PAWCATUCK RIVER AT WESTERLY, R.I.
D.A. = 295 SQ. MI.
19 NOV. 1976
17
18
19
20
21
22
23
24
25
MARCH 1968

PLATE 1-9



DISCHARGE - C.F.S.
2000
1000
0
11
12
13
14
15
16
17
18
MARCH 1968


PAWCATUCK RIVER BASIN
MARCH 1968 FLOOD HYDROGRAPHS
GAGE 75 PAWCATUCK RIVER AT
WOOD RIVER JUNCTION R.I.
D.A. 100 SQ MI. 19 NOV. 1976
17
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19
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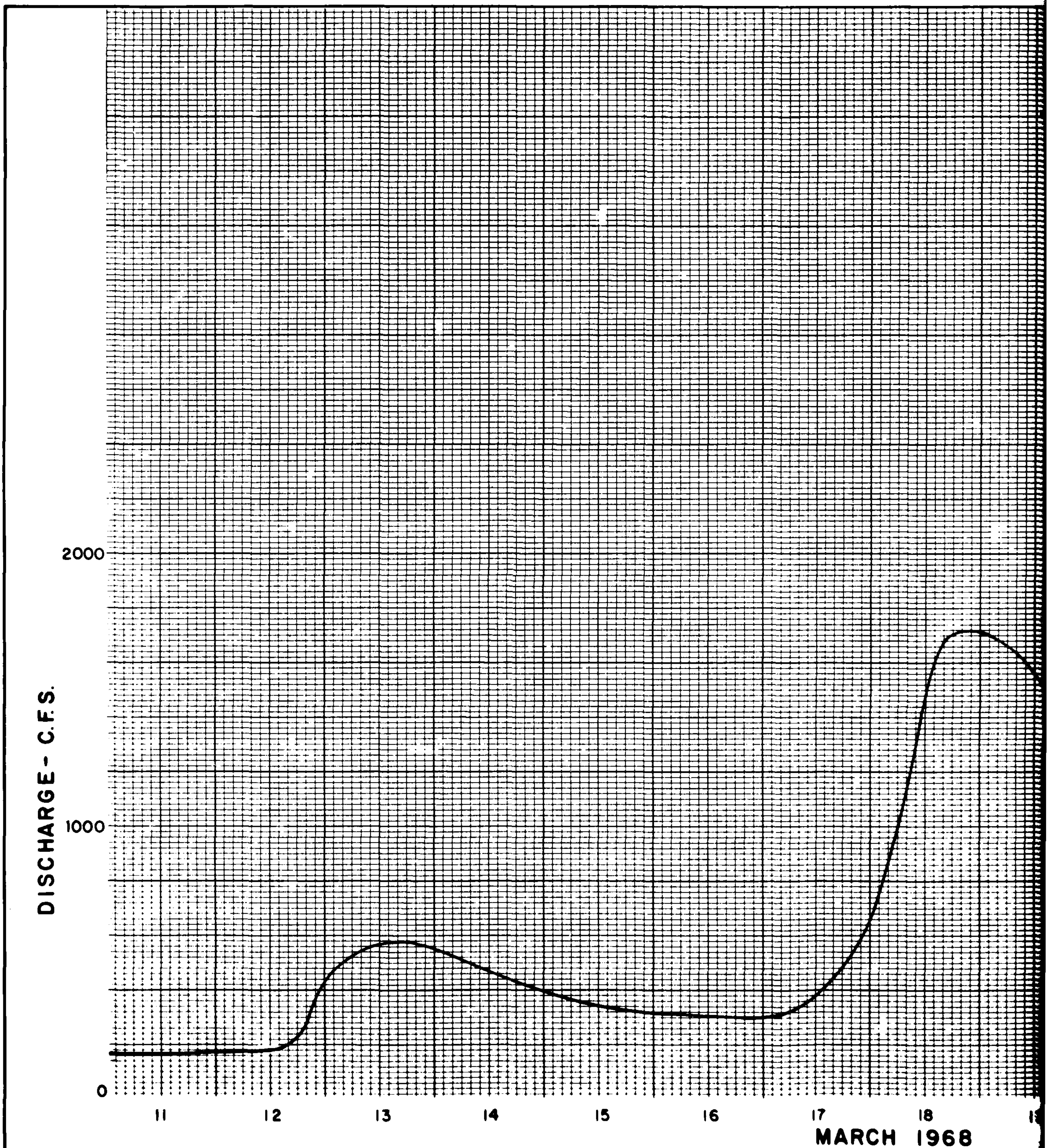
25
MARCH 1968

PLATE I-10

2



DISCHARGE - C.F.S.
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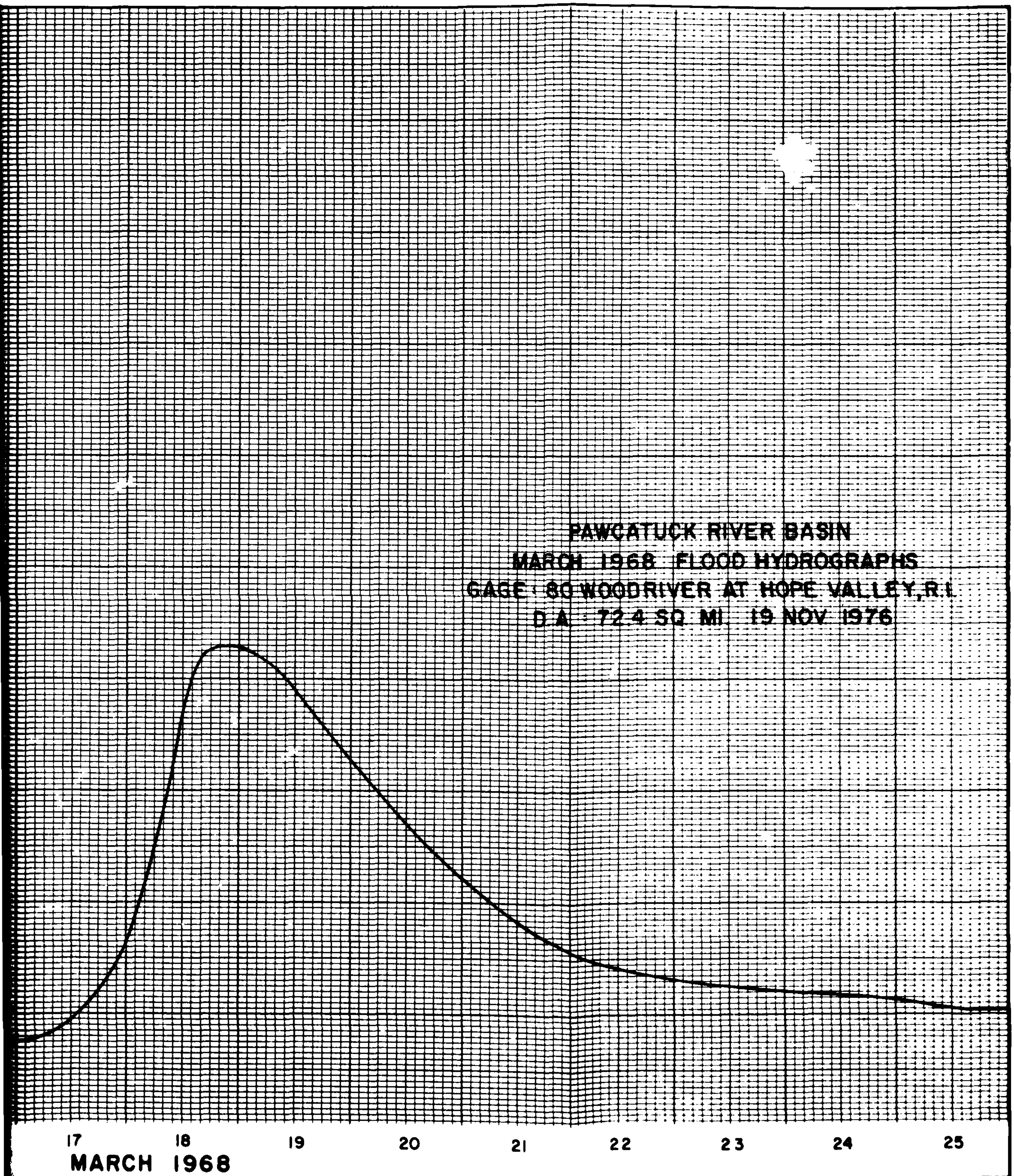
1000
0
11
12
13
14
15
16
17
18
MARCH 1968



PAWCATUCK RIVER BASIN
MARCH 1968 FLOOD HYDROGRAPHS
GAGE: 80 WOODRIVER AT HOPE VALLEY, R.I.
D.A. = 72.4 SQ. MI. 19 NOV 1976
17
18
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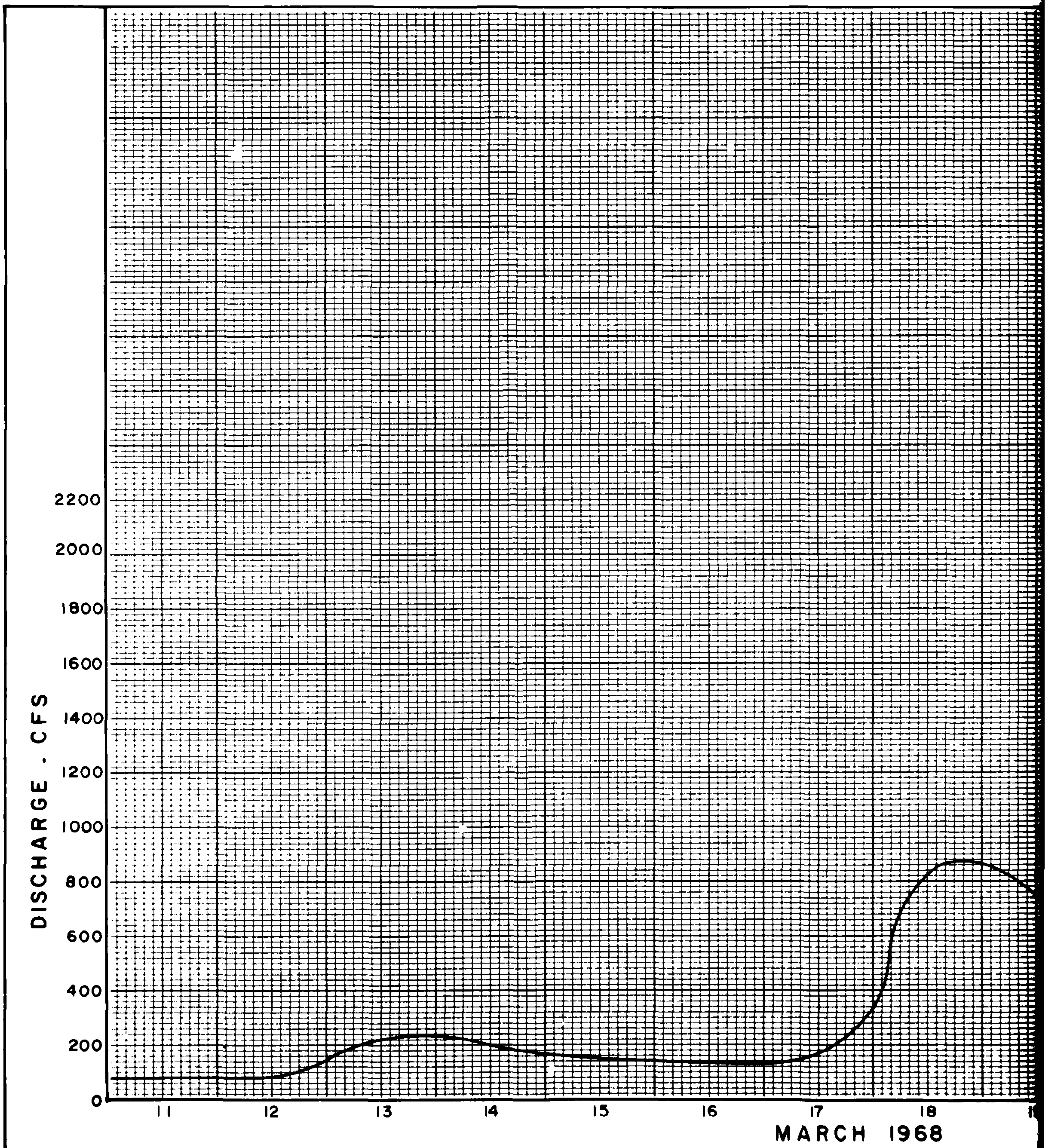
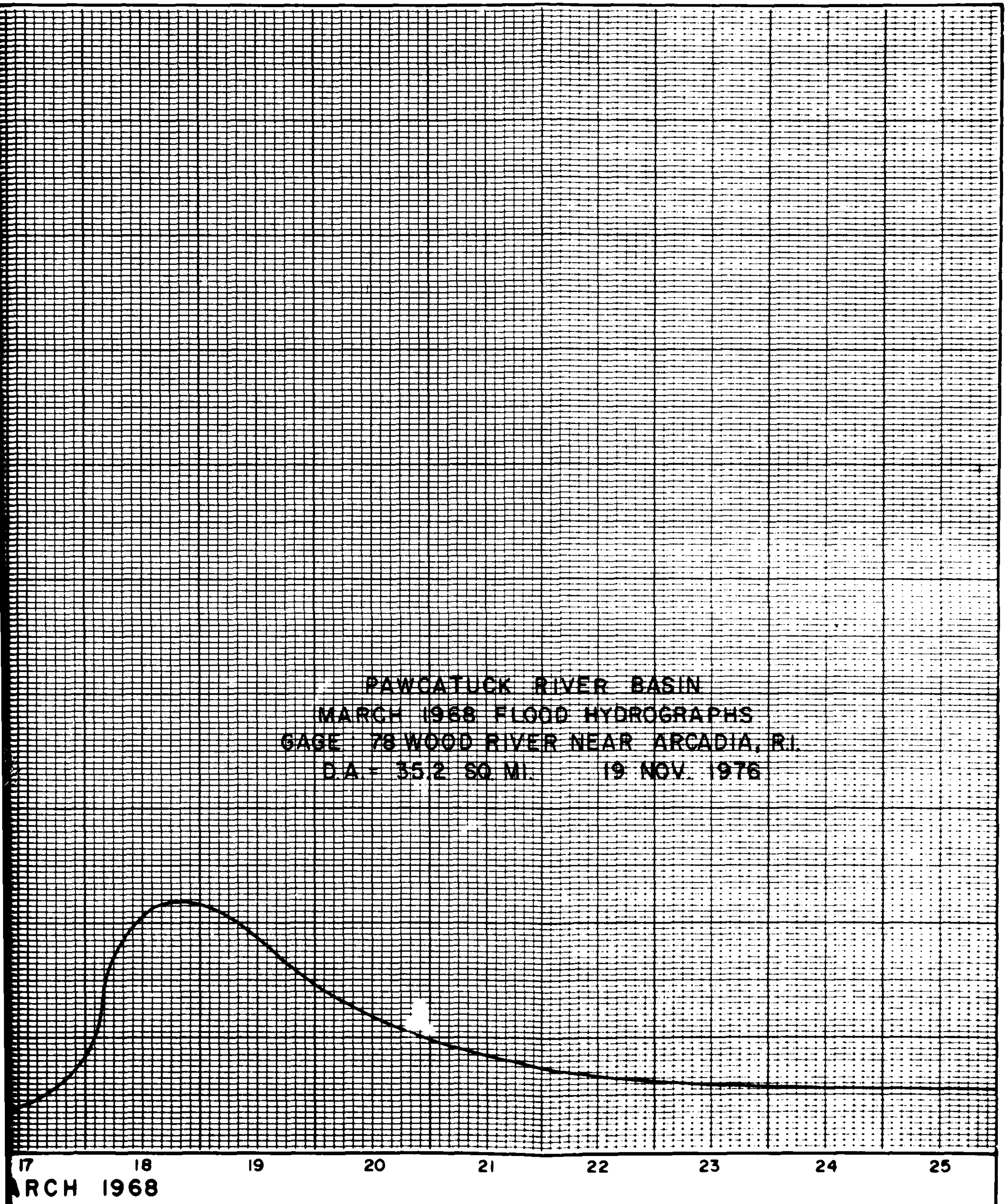
MARCH 1968

PLATE I-11



2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
DISCHARGE . CFS
11
12
13
14
15
16
17
18
MARCH 1968


PAWCATUCK RIVER BASIN
MARCH 1968 FLOOD HYDROGRAPHS
GAGE 78 WOOD RIVER NEAR ARCADIA, R.I.
D.A = 35.2 SQ MI. 19 NOV. 1976
17
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RCH 1968

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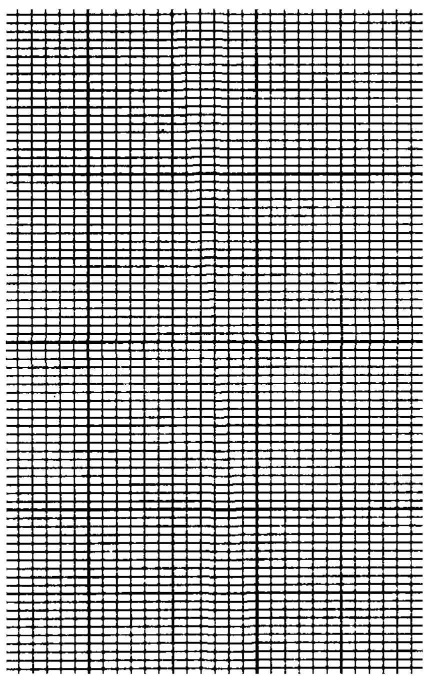
PLATE 1-12



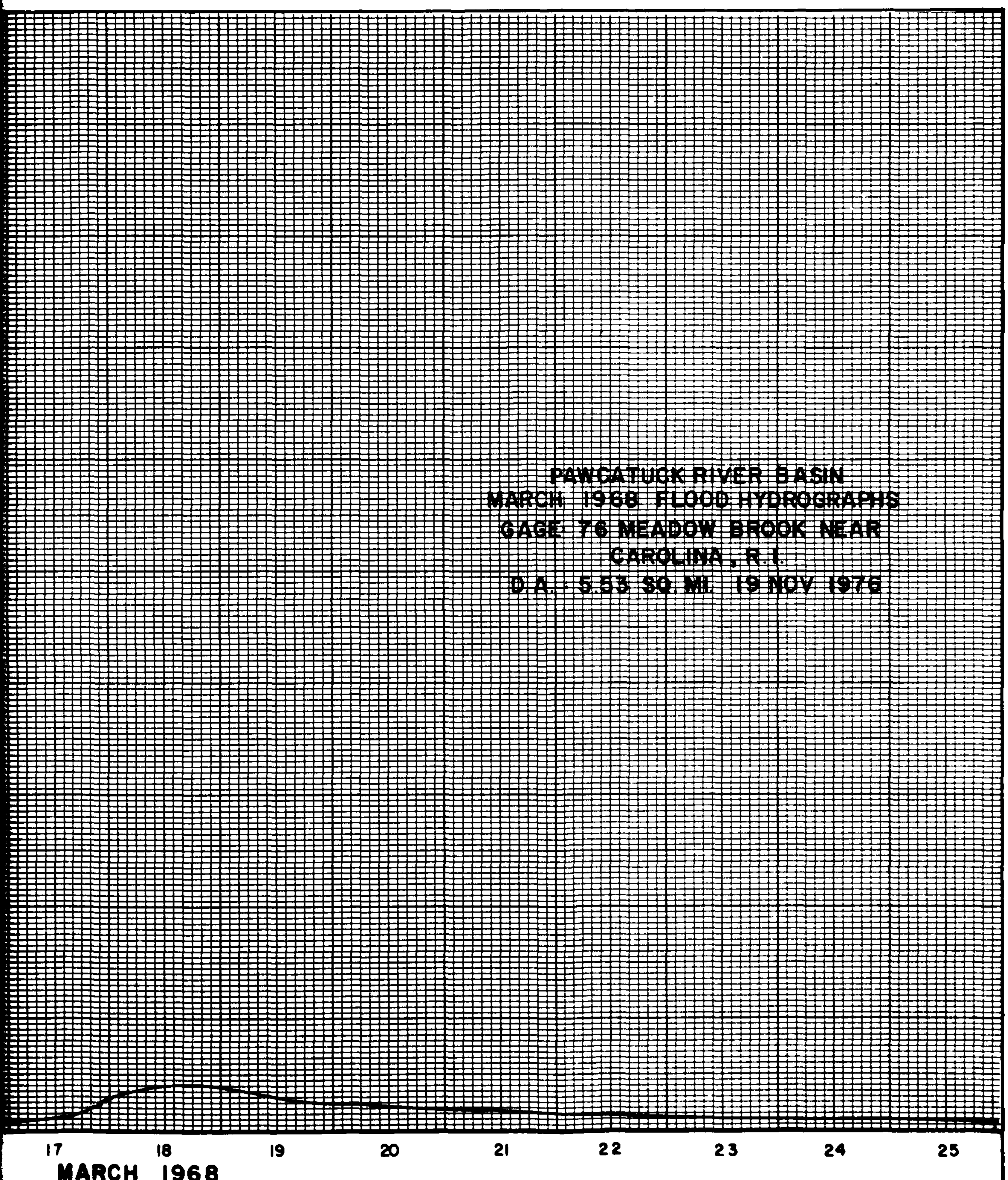
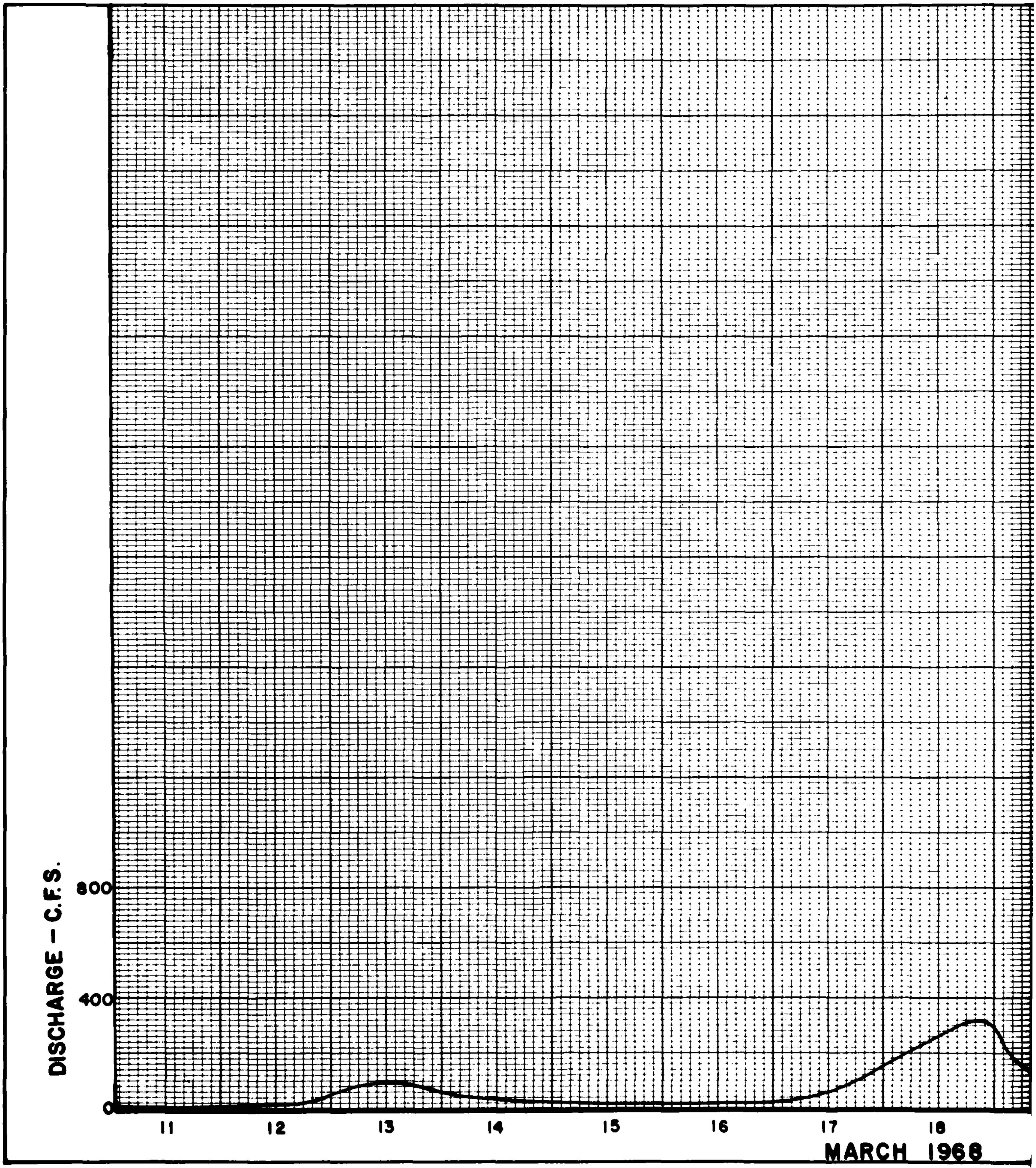
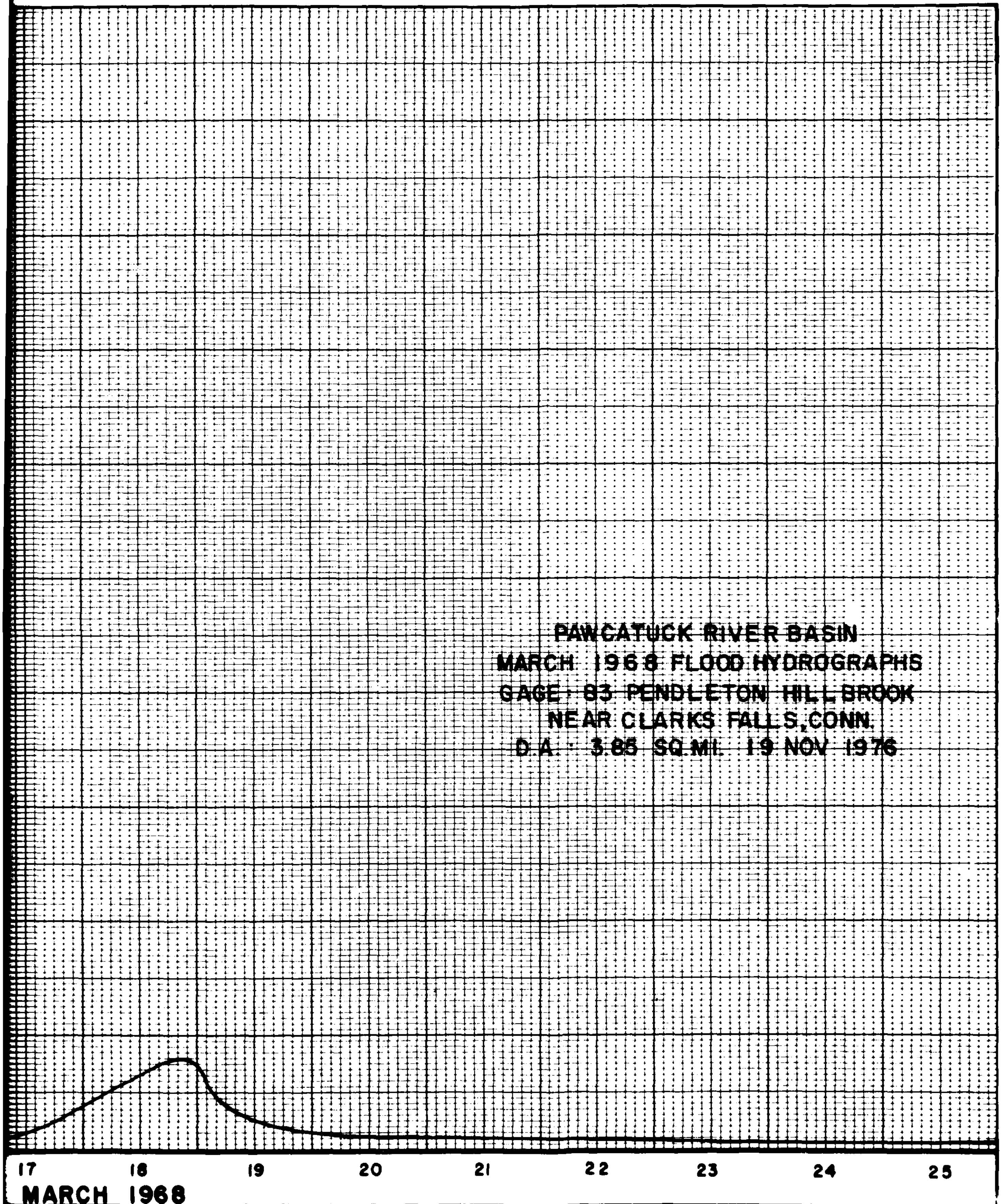

PAWCATUCK RIVER BASIN
MARCH 1968 FLOOD HYDROGRAPHS
GAGE 76 MEADOW BROOK NEAR
CAROLINA, R.I.
D.A. - 5.53 SQ. MI. 19 NOV 1976
17
18
19
20
21
22
23
24
25
MARCH 1968

PLATE 1-13

2


DISCHARGE – C.F.S.
800
400
0
11
12
13
14
15
16
17
18
MARCH 1968


PAWCATUCK RIVER BASIN
MARCH 1968 FLOOD HYDROGRAPHS
GAGE 83 PENDLETON HILL BROOK
NEAR CLARKS FALLS, CONN.
D.A. 3.85 SQ.MI. 19 NOV 1976
17
18
19
20
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MARCH 1968

2

PLATE I-14

The peak of the wind-induced tidal surge of the hurricane of September 14, 1944 arrived about 3 hours before the time of the predicted low tide and caused only moderately high stages in the Pawcatuck basin. The water reached an elevation of 3.6 feet ngvd at Block Island, 6.6 feet ngvd at the mouth of the Pawcatuck River, and 7.6 feet ngvd at Pawcatuck, Connecticut. The center of the storm passed inland between Charlestown and Point Judith, Rhode Island, (15 miles east of Pawcatuck) at 10:20 pm EST. It then continued in a northeasterly direction veering out to sea at Boston, Massachusetts. The minimum recorded barometric pressure in New England during this storm was 28.30 inches of mercury at Westerly, Rhode Island. The forward speed of the storm near Block Island, Rhode Island, was bout 30 knots (34 mph).

At 1 minute sustained velocity of 88 miles per hour from the southeast was recorded at Block Island with maximum gusts in excess of 100 mph. Isovel charts and wind direction as they occurred as shown at 3 hour intervals in the previously referenced chart. These charts indicated that a maximum sustained wind velocity of 65 mph from the west occurred about 1 hour before the peak still water level, whereas an hour after the peak still water level, the maximum sustained wind velocity was less than 30 miles per hour from the northeast.

Typical flooding at Pawcatuck caused by the combination of freshwater flow and tidal backwater, at the U.S. Geological Survey Gage, occurred during the 1954 Hurricane "Carol." This hurricane caused tidal flood levels at the mouth of the Pawcatuck River about 0.7 foot below the September 1938 flood levels. The tidal surge of 8.2 feet arrived near the predicted normal high tide of 1.5 feet ngvd and reached a maximum still water level of 9.7 feet ngvd. The peak river discharge of 1,340 cfs occurred one day after the tidal flooding when the river elevation of 4.2 feet ngvd at the gage was unaffected by the tide.

The center of this storm crossed the south shore of Connecticut in the vicinity of New London (14 miles west of Pawcatuck) at about 10:30 am, EST on 31 August and then followed a northerly path across New England. The minimum barometric pressures in New England during this hurricane were 28.20 inches of mercury at Storrs, Connecticut, (35 miles northwest of Pawcatuck) and 28.26 inches of mercury at New London. The forward speed of the hurricane was about 40 knots (46 miles per hour).

Peak gusts measured during Hurricane Carol were 142 mph at Mount Washinton, New Hampshire and 135 mph at Block Island, Rhode Island. Isovel charts and wind directions at 2 hour intervals were calculated for the Long Island and Block Island Sounds. From these charts it is estimated that a maximum velocity of approximately 80 mph from the southwest occurred in the Block Island Sound area and about 60 mph from the southwest at the mouth of the Pawcatuck River.

Heavy rains accompanied Hurricane "Diane" on 19 August 1955, falling on ground previously saturated by precipitation accompanying Hurricane "Connie" during the previous week (11-15 August). In less than a 2 day period, over 6 inches of rain were recorded in Providence. Nevertheless, the total runoff as measured at the Centerdale stream gaging station represented only 0.4 inches of runoff for the entire 38.3 square miles of drainage. Flooding in the Pawcatuck River Basin was minimal.

Hurricane "Donna," September 12, 1960, skirted the Atlantic Coast in a northeasterly direction from Florida to Long Island to New England. Although tides were raised 5 to 10 feet above normal levels, coastal flooding damage was minimized since the highest surge caused by the storm did not coincide with the time of the highest astronomic tide. Timely and accurate forecasts and warnings were issued which also helped minimize the loss of life and property during this storm.

Nearly half of the total damages occurred in coastal areas. Damages included coastline and seawall erosion and destruction of cottages, hundreds of boats and fishing and lobstering gear. In addition to wind and wave action, salt spray along the coastal seriously damaged foliage and adversely affected later development of the usually brilliant fall coloration. Power service was interrupted to a large proportion of houses in this area when utility lines were destroyed. However, most interruptions of power were of relativley short duration.

Severe tidal flooding causing serious damage occurred during the 1938 and 1954 hurricanes. The Corps estimates recurring hurricane flood damages (at June 1978 prices) for the four coastal municipalities at nearly $10.3 million for the 1938 hurricane, and $28.4 million for a recurrence of the 1954 hurricane. The Pawcatuck Hurricane Flood Protection Project in Stonington, Connecticut will afford protection to an ara of 31 acres which experienced severe damages in 1938 and 1954.

Typical flooding at Pawcatuck caused by the combination of freshwater flow and tidal backwater, at the U.S. Geological Survey gage, occurred during the 1954 Hurricane Carol. This hurricane, on 31 August 1954, caused flooding to elevation 10.4 feet ngvd at the gage while the river discharge was rising. The peak river discharge of 1,340 cfs occurred 1 day after the tidal flooding when the river elevation of 4.2 feet ngvd at the gage was unaffected by the tide. There was no tidal effect during Hurricane "Edna" 11 days later on 11 September 1954. A discharge of 3,340 cfs caused the river to reach an elevation of 7.2 feet msl at the gage 1 day after Hurricane "Edna" passed.

In the Fishers Island Sound and Little Narragansett Bay area there is a mean tide range of 2.5 feet (a mean low water of -1.5 feet ngvd and a mean high water of 1.0 feet ngvd). Spring tides have an average range of 3.1 feet and a maximum range of about 5.1 feet. A maximum spring tide will reach an elevation 4.0 feet above mean low water (1.5 feet above mean high water).

The tides in Little Narragansett Bay at the mouth of the Pawcatuck River are subject to meteorological influences such as changes in atmospheric pressure and strong winds, besides the normal gravitational effects of the sun and the moon. On the Atlantic coast, it is generally assumed that a drop in barometric pressure of 1 inch of mercury will cause about a 1 foot rise in water levels. Normal winds within the bay have little effect on the tide levels but during coastal storms tide levels often buildup several feet above the predicted elevations. When a severe storm occurs with strong southerly winds, the observed tide far exceeds predicted elevations. A summary of recent notable storms and associated high tides is shown on Table 1-15.

Future Conditions - In the past, riverine flooding has not caused extensive damage in the nontidal portion of the Pawcatuck River Basin. This cannot be construed, however, to mean that damage will never occur. As developmental pressure continues to increase throughout the area, more wetland areas will be lost. This loss of wetlands will increase the potential for flood damages in areas that were not previously flood prone.

Normally, the rate at which runoff enters the river or stream increases as the amount of devlepment increases. Rainfall in built-up areas, rather than permeating into the ground, will result in virtually instantaneous runoff and will quickly enter the river or stream.

Economic projections indicate that there will be a population increase of about 55 percent in Rhode Island by 1990. Proper planning can allow economic growth to continue while limiting the detrimental effect of that development. By carefully controlling development in the area, it is possible to allow for either an economic or environmental future and still maintain the environmental integrity of the area.

The Pawcatuck area has abundant ground water resources and is expected to be able to supply its own mid to long-term water needs. Currently proposed municipal wastewater treatment plant construction in Westerly, Stonington, Pawcatuck, and Hope Valley should help upgrade the water quality in problem areas. Generally high quality water is expected to be maintained throughout the Pawcatuck basin.

Public and privately owned recreation and conservation land is abundant in the Pawcatuck area, however, public access to many waterfront recreation areas is often limited. According to the Heritage, Conservation and Recreation Service (HCRS) these resources will more than satisfy the 1990 demands of area residents for hiking, nature study, and photography, and a large portion of their demands for camping. About 22,400 acres are publicly owned and open to hunting; another 66,000 acres are privately owned and open to hunting. However, due to the close proximity of the Pawcatuck basin to the Providence metropolitan area, much of the hunting demands of that city will be diverted to this area.

Existing Plans and Projects - The most current project in the basin is the local protection project at Pawcatuck in the town of Stonington, Connecticut on the west bank of the Pawcatuck River. The project begins about 0.7 mile south of the U.S. Route 1 Bridge and extends about 2,200 feet northward along the west bank of the river before turning westward to tie into the railroad embankment west of Mechanic Street. The protection consists of 1,915 feet of earthen dike, 940 feet of concrete wall, two vehicular structures and a pumping station. Construction was completed in 1963. Operation and maintenance of the project is the responsibility of the town of Stonington.

The project affordsd protection to an industrial area of 31 acres, in which are located 2 plants that experienced severe damages in the September 1938 and August 1954 hurricanes.

Initiated in 1871 and modified under subsequent authorization of 1885 and 1896, the original navigation project provided for a channel 5 to 8 feet deep through Liitle Narragansett Bay and up to the Pawcatuck River for about 5 miles to the center of Westerly. The project area includes Little Narragansett Bay, Pawcatuck River and Watch Hill Cove. The Bay is entered at its extreme western end, near Stonington Point, and the main channel extends generally eastward across the Bay to the mouth of the Pawcatuck River. Watch Hill Cove is located at the southeastern end of the Bay in Westerly, Rhode Island. The original work was completed in 1903.

Work performed under an existing project, authorized in 1896 and modified in 1905 and 1945, consisted of the following: the bay and river channels were dredged to 10 feet, a 10-foot channel and anchorage basin were dredged at Watch Hill Cove and a jetty was constructed near the southwest corner of the basin. This work was completed in 1963.

WOONASQUATUCKET RIVER BASIN

Existing Condtions - Flooding in the basin can occur at any time of the year. Historical flooding has been reported to dates in the early 1800's. Since that time numerous flood producing storms have been experienced. As mentioned earlier the area is adjacent to the Providence metropolitan area in close proximity to the seacoast, and well serviced by the highway systems. Hence the lower and middle portions of the basin have become captive to the demands imposed by urbanization.

Urbanization may significantly change the watershed's response to precipitation which can result in substantially higher peak rates of runoff. The degree of change depends upon several factors; the amount of new paving or rooftop; the addition of local drainage conveyances; the loss of natural valley storage areas. If a large residential development is placed in a formerly wooded area, the overall changes in runoff rates would probably be minor. The towns zoning laws establish the minimum lot size. Hence, assuming a 12,000 square foot building lot, the amount of

TABLE 1-15

SUMMARY OF RECENT NOTABLE STORMS THAT CAUSED HIGH TIDES ALONG THE CONNECTICUT COAST

Date of Storm	Remarks
1966, Dec. 29	Tide rose to 5.9 feet above National Geodetic Vertical Datum at Pawcatuck, Connecticut.
1968, Nov. 12	Tide rose to 6.3 feet above National Geodetic Vertical Datum at Pawcatuck, Connecticut.
1977, Nov. 26	Tide rose to 6.3 feet above National Geodetic Vertical Datum at Pawcatuck, Connecticut.

impervious area added is relatively minor. A typical new home, a raised ranch with garage under, is generally 44'x26' or 1,144 square feet. A typical driveway would be 40 feet by 10 feet or an additional 400 square feet, for a total impervious area of about 1550 square feet, or an increase of about 13 percent. For a minor rainfall, the runoff from the newly developed area would be greater, as the area now has a greater impervious percentage. This would yield a slightly higher flow, but would not create a flooding condition unless severely undersized culverts are in the waterway system. As the rainfall event increases in both intensity and duration, the impervious factor decreases in importance. This is due to the creation of "excess rainfall". The rainfall eventually gets to an intensity/duration where the natural soil may no longer absorb it. At this point in time, it too acts as impervious area and most, if not all, of the future rainfall is conveyed to the nearest waterway. This later condition is what creates virtually all of the riverine flooding conditions. Snowpack and frozen ground conditions can add to the flood problems.

Industrial-commercial development is different in the problems it may create to the downstream areas. Obviously, major industrial-commercial complexes are much larger. Virtually the entire land area is impervious, approaching 90 to 100 percent impervious in some instances. All rainfall is immediate runoff. The additional problem created by such complexes is that the runoff is now increased in velocity as the friction factors are significantly lower. Water runs off asphalt much faster than over a saturated forest area. This corresponds to a greater water depth that can be anticipated, unless storage basins are created in the industrial-commercial complex.

Filling in of wetlands results in less storage available in the area to hold flood runoff. If the filled area is significant, or placed in a restrictive portion of the natural stream channel, higher flood heights both upstream and downstream are possible. Such key areas are usually identified on flood insurance rate maps if the municipality participates in the regular program of the National Flood Insurance Program as the floodway.

Although considerable portions of the lower basin are already approaching a completely urbanized appearance, development is occurring in the middle and upper basin. The municipalities should ensure that the developer take into consideration in his designs the flooding effects that could be created. Wise development should not pose any increase in flooding conditions.

Along the mainstem of the Woonasquatucket, flooding can be directly associated with poor channel maintenance, flood plain encroachment, inadequate channel capacity and inadequately sized bridge openings.

The West River has a very significant flood problem. The river originates along the border of the towns of Lincoln and Smithfield. It flows for a distance of 6.8 miles to its confluence with the Moshassuck. Development in the West River sub-basin has been much more rapid than in the Moshassuck. In the upper portion development has been of a residential nature with a few scattered commercial centers. The lower portion of the West River has been developed for industry and manufacturing. In order to provide for this growth, swamps or lowlands were filled in, and streams channelized. Some of the channels have even been filled in further reducing the flow carrying capacities of the stream. In several instances, dams were breached on old ponds and the lands reclaimed to be built upon. These trends coupled with the increased runoff characteristics of the basin contribute to the nearly annual flooding the area receives.

The areas which consistently experience significant flooding and losses are the 2 large industrial/commercial complexes in Providence at 387 Charles Street and 725 Branch Avenue.

The Moshassuck River begins in Lincoln and flows 7.2 miles southerly to its confluence with the Woonasquatucket River in Providence. The upper portion of the basin is rural and in the past has not had many reported instances of damages due to riverine flooding. Moderate losses have been experienced in the lower two thirds of the basin. However, most of the industrial-commercial establishments have been built out of the areas normally inundated by moderate flood events.

The flood history of the basin demonstrates that major floods can occur any season of the year as a result of intense rainfall alone or in combination with snowmelt. The magnitude of freshwater flooding on the Woonasquatucket River is a function of storm rainfall and the resultant run-off from the 36.9 square miles of drainage downstream of the large impoundments mentioned above, as well as the magnitude and timing of the discharges of the initial storage capacity in these impoundments.

One of the earliest known floods, the greatest on record, occurred 11 through 14 February 1886. Approximately seven to eight inches of rainfall combined with substantial snowmelt (water equivalent of two inches) produced flood levels six to seven feet higher than any historical flood either before or after this event. While there was no measured flow data to accurately record the flood event it is estimated that the rate of runoff was 4000 cfs near the USGS gage location.

During the storm of 3-4 November 1927 between three and six inches of rainfall was reported for this drainage area. Precedent conditions favored a fairly rapid runoff. The result was a minor flood that produced some relatively insignificant damages in several isolated areas.

Between 12 and 19 March 1936, a storm produced heavy rainfall and unseasonally high temperatures throughout New England. A deep snowcover in most areas provided considerable snowmelt which combined with the rainfall-runoff produced some of the largest flood flows throughout New England. The Woonasquatucket Basin was east of the center of this storm and consequently was not subjected to the excessive precipitation that some other New England areas received. Approximately 7.5 inches of rainfall was recorded between 9-22 March for the Woonasquatucket drainage area with very little, if any, snowcover. Conditions were such that estimated runoff was 70 to 80 percent of the rainfall. Stillwater, Slack and Waterman Reservoirs stored a considerable portion of the floodwaters thereby reducing the crest. The estimated peak discharge for this event was 28.0 cfs per square mile of drainage area.

The flood of 17-19 March 1968 was the result of a heavy rainfall on ground saturated by a previous storm of 12-13 March. Runoff from melting snow, together with the new precipitation contributed to severe flooding. The area below the U.S. Geological Survey gaging station experienced moderate flood damage. Due to the upstream urbanization, under todays conditions it is prone to even greater damage.

In the past, tropical storms of hurricane force have produced extensive tidal flooding in the lower reaches of the Woonasquatucket River Basin. Over the last 300 years, approximately 71 such storms have passed over this area, 13 causing tidal flooding, and 25 causing moderate flooding. Since 1965, the major portion of the lower basin has been protected by the Fox Point Hurricane Barrier, located at the mouth of the Providence River.

Heavy precipitation, often of torrential proportions, usually accompanies a hurricane and in some cases will arrive several days in advance. Examples of rainfalls coincident with hurricanes include September 1938, September 1944, September 1954 (Edna) and August 1955 (Diane).

The hurricane of 17-22 September 1938 produced abnormally high tide levels in Narragansett Bay, approximately 15.7 feet above mean sea level in the vicinity of the mouth of the Woonasquatucket River. Resulting tidal flooding affected the lower reaches of the river. The greater part of the rainfall associated with this storm occurred during the four day period prior to the hurricane as it crossed the coast of Connecticut. Despite significant rainfall, the upper basin impoundments were low, therefore were capable of storing the runoff. Freshwater flows from the uncontrolled drainage areas did not play a major role in contributing to experienced flood levels.

Hurricane "Carol" passed over the area west of the basin on 31 August 1954. Maximum tidal elevation at Providence, Rhode Island was 14.7 feet above mean sea level. Winds gusted over 100 mph at Providence during this storm. Precipitation ranged between 2 and 4.5 inches over the basin

consequently, freshwater flooding was insignificant. Providence experienced less than three inches of rainfall but was damaged by the hurricane tidal surge which inundated the city.

Heavy rains accompanied Hurricane "Diane" on 19 August 1955, falling on ground previously saturated by precipitation accompanying hurricane "Connie" during the previous week (11-15 August). In less than a two day period, over six inches of rain were recorded in Providence. Nevertheless, the total runoff as measured at the Centerdale stream gaging station represented only 0.4 inches of runoff for the entire 38.3 square miles of drainage. The peak discharge for the entire basin at the mouth of the Woonasquatucket River was estimated to be about 6,400 cfs.

Flood Damage Survey. Estimates of potential flood damage along the Woonasquatucket River in Providence were determined by a damage survey conducted during June 1977. New England Division, Corps of Engineers, analysts collected data on the extent and nature of the areas flooded, the depth of flooding and the amount of damage experienced at each damage site during the flood of 1968.

Estimates of potential flood damages along the Moshassuck and West River were also determined by a damage survey conducted by an architect-engineer firm who compiled the data and was supervised by the New England Division for consistency with previously prepared damage surveys. Damages were related to height above ground level at the particular structure due to the relative lack of factual data supporting flood heights experienced during March 1968.

Recurring Losses. For the portion of the Woonsaquatucket surveyed, recurring losses were summarized by stage at each damage site. It was estimated that recurring losses for a flood at the level of the March 1968 flood would be approximately $3,170,000. The largest share, 76.9 percent, would be in damages to industrial property with a remaining 12.5 percent in commercial property damage and 5.6 percent in residential home damage, and the rest in damages to utilities, railroads, highways, bridges and public properties.

The +5 stage is designated at five feet above the March 1968 flood level. Recurring losses at this stage would be approximately $55,700,000. Recurring losses are shown in Table 1-16.

Due to the lack of data for the March 1968 flood, recurring losses for the West-Moshassuck Rivers have been related to the January 1979 flood with a frequency of occurrence of approximately 5 years. It was estimated that recurring losses for the January 1979 flood would be $800,000 at 1981 price levels. This is equal to 84 percent industrial, and 16 percent commercial. Recurring losses associated with the 100-year flood total $12,852,000 at 1981 price levels.

TABLE 1-16

WOONASQUATUCKET RIVER
RECURRING LOSSES
BASED ON 1977 DAMAGE SURVEY
UPDATED TO 1981

Property Type	March 1968 Flood Level (0 Stage) Losses (x $1000)	March 1968 Flood Level (0 Stage) Percent Of Total	Five Feet Above the 1968 Flood Level (+5 Stage) Losses (x $1000)	Five Feet Above the 1968 Flood Level (+5 Stage) Percent Of Total
Residential	$179	5.6	$2997	5.4
Commercial	397	12.5	10896	19.6
Industrial	2438	76.9	39074	70.1
Public	30	1.0	53	0.1
Utilities, Railroads Highways & Bridges	128	4.0	2694	4.8
TOTAL	$3172	100.0	$55714	100.0

TABLE 1-17

FLOOD DAMAGES - '79 FLOOD LEVEL
WEST RIVER - PROVIDENCE

Based on 1977 Damage Survey
Updated to 1981

Property Type	Losses (x $1000)	Percent Of Total
Industrial	$672.0	84
Commercial	128.0	16
Residential	0.0	0
	$800.0	100

Average Annual Losses. To determine average annual losses, a "stage-damage curve" was plotted from the summary of recurring losses. Hydrologic stage-frequency data was combined with the respective stage-damage data to extract the relationship between dollar damages at a given stage and the frequency of an event. The average annual losses were determined from this "damage-frequency curve." The average annual losses on the West River are $924,000 and on the Moshassuck these losses are $80,500.

Future Benefits. Due to economic growth limited by the lack of vacant and buildable land, the intensification benefit would be minor for the Woonasquatucket River flood plain in Providence. Inundation reduction benefits due to affluence which would accrue to residences are equally small. Residential growth in the flood plain is not expected.

Economic activities do not consider possible flooding as a factor in locating in the flood plain of the Woonasquatucket River in Providence. There are businesses locating in vacated structures at the present time. These new occupants are economically comparable to the previous occupants.

Calculation of future benefits due to economic growth for the Woonasquatucket River is warranted only if they would result in a significant change in benefit-cost ratio.

Future Conditions - The basin's planning area towns contain a relatively meager amount of land available for recreational use. Roughly equal portions of 2,600 acres of recreational land is owned by the State, municipalities and private interests. This constitutes approximately 5.8 percent of the watershed's total land area. The Woonasquatucket and its banks are infrequently used for outdoor recreation. The banks are principally developed for industrial, commercial and residential use. In addition, the river is severely polluted at the present time. Consequently, the lands immediately adjacent to the Woonasquatucket River have limited potential for recreational development. The Moshassuck River presents a similar situation. The Heritage and Conservation Resources Service (HCRS) estimates that by 1990 only 14 percent of the demand for fresh water beaches, 20 percent of the demand for picnic facilities and 25 percent of the demand for accessible natural areas will be met. As tourism in the Providence metropolitan area increases and development within the basin continues, this demand will be inflated further.

Although there are a modest number of fresh water ponds within the basin, availability for fish and wildlife recreation is limited. Unfortunately, pollution has greatly reduced the quality of many ponds and streams making them insufficient to support substantial fish life, if any. In addition, of those areas of acceptable water quality, private ownership of adjacent lands blocks access to many of them. Hunting facilities are faced with similar deficiency.

A substantial portion of the Woonasquatucket-Moshassuck River is urbanized, approximately 33 percent as estimated by the U.S. Department of Agriculture, Soil Conservation Service, in March 1975. With the exception of Providence, the communities of the basin experienced a rapid population growth rate of 22.3 percent between 1950 and 1970. This increase consumed much land previously available for natural resources. As considerable future growth is projected, it must be guided to developable lands to insure the critical remaining environmental resources are protected.

The Providence Water Supply Board provides three of the four principal basin communities with water - Providence, North Providence and Smithfield. The fourth community, Lincoln, has its own water system using wells along the Blackstone River. In 1970, the basin had a population of 232,000 and they consumed 37 million gallons per day (mgd). By 1990 projections indicate an increase in population to about 245,000 requiring 47 mgd. By 2020, approximately 60 mgd will be needed to supply almost 300,000 people.

In addition to the basin area population growth, the projections show that future demands for public water supply are growing at a steady pace and shall continue in the future.

The basin lies within a zone where precipitation is well distributed throughout the year. Extended periods of dryness have been recorded, however, which frequently affect streamflow and surface and ground water supplies. Prior to 1936 rainfall data is sparse. Since the establishment of gaging stations, significant droughts have occurred between 1941 and 1944, 1948 and 1950 and 1963 and 1966. This latter period is the most severe on record and had a significant impact on the water resources of the region. Ground water provides the primary source of streamflow between periods of rainfall. Ground water storage is generally replenished during each spring runoff and rarely is a deficiency of this source carried over from one year to the next.

NARRAGANSETT BAY LOCAL DRAINAGE

Existing Condtions - Inland flooding damages in the Narragansett Bay local drainage area have been minimal. The flat topography and relatively broad flood plains of the surrounding area adequately modify flood flows, thereby reducing flood stages. The abundance of wetlands, which provide significant natural valley storage, and the low development density of the flood plain also help lessen flood damage costs. Loss of these existing natural valley storage areas and increased development in the flood plains could result in more frequent and serious flooding in the Narragansett Bay area.

The greatest concentration of damages due to hurricanes usually occurs within the city of Providence. The east bank of the Providence River has experienced heavy industrial damages. Losses occuring in the Providence Harbor area due to the hurricanes of 1938 and 1954 have included a yacht club, docks, boatyards, tanks and oil refineries. Heavy damages could occur from Fields Point north to the Fox Point Barrier.

Along the Cranston shoreline, boats and yacht clubs have been demolished by hurricanes. Another heavily damaged area, the Warwick Industrial Park, is located along the tidal reach of the Pawtuxet River. This area has been thoroughly covered in the Pawtuxet River Interim Report. Also in Warwick, in the Shawomet and Oakland Beach sections, many homes and cottages were leveled during the 1938 hurricane. Oakland Beach and Buttonwoods, both heavily developed residential areas, are directly in the path of any storm coming into Narragansett Bay. In the event of a storm of the magnitude of the 1938 hurricane, Apponaug Cove and surrounding areas would experience high industrial losses. Heavy residential damages to about 90 cottages and year-round homes would result at Sandy Point on Potowomet Neck, and also similar losses would occur at Buttonwoods and Warwick Cove.

In North Kingstown, losses due to the 1954 hurricane included extensive damage to facilities at the U.S. Naval Reserve Quonset Naval Air Station and the Naval Construction Battalion Center at Davisville; however, both have been almost completely closed down at this time. Also numerous homes and commercial establishments in the ara suffered considerable damages. Flooding could also affect homes located in Shore Acres, a relatively low, flat point that extends into Wickford Harbor.

Destruction of the Narragansett waterfront has been serious due to past hurricanes, particularly along the Narragansett Pier. The East Shore Ferry Station in Jamestown Harbor has been badly damaged during past hurricanes and many cottages on East Shore Drive have been totally destroyed. Virtually all have been rebuilt at the same approximate elevations.

East Providence has experienced industrial and commercial losses mainly in the vicinity of the Wilkes-Barre Pier and Bold Point. Bullock Point, also in East Providence, has experienced heavy residential losses to year-round homes. This is also true of the Allen Neck section of West Barrington and Rumstick Neck and Adams Point in Barrington. The Warren River, particularly along the low, flat eastern shoreline, is subject to tidal flooding causing considerable industrial and commercial damages. Several manufacturing firms have sustained severe tidal flooding in past hurricanes.

Heavy waterfront losses in Bristol Harbor have included boatyards, docks and harbor facilities, and summer homes and cottages. Overflow of the tidal reach of the Taunton River has been substantial, affecting the towns of Dighton, Somerset, Berkley, Freetown, Swansea, Taunton and Fall River, Massachusetts. South Swansea is flooded by both the Mt. Hope Bay and the tidal reach of the Lees River. The southern and northwestern shorelines of Aquidneck Island have been heavily battered by hurricane tides of Narragansett Bay and the Sakonnet River. Newport Harbor, Island Park in Portsmouth and the long, exposed, southern shoreline at Newport Neck have sustained heavy damages in the past. In the vicinity of Long Wharf, flooding occurred as much as 2,000 feet inland in 1954, flooding

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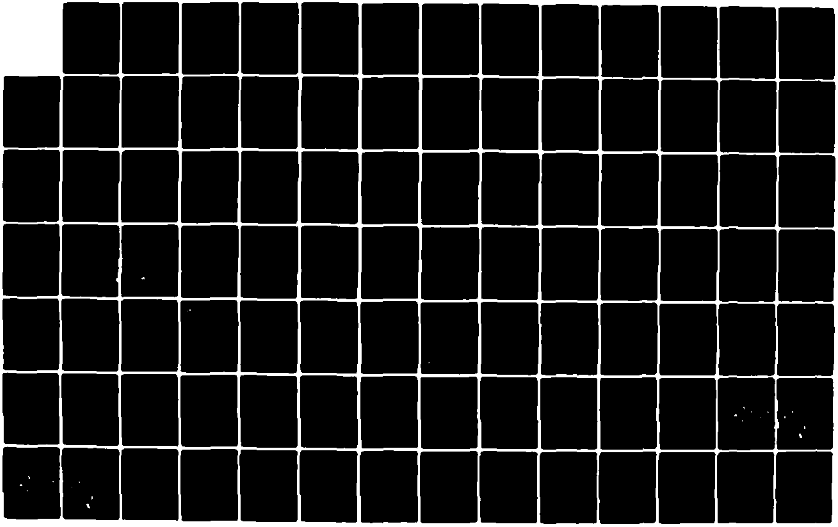

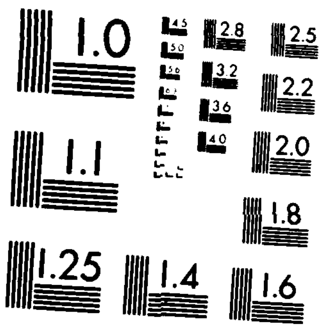
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numerous houses, stores and warehouses. Recreational and commercial boats were destoryed and beaches and cottages along the southern shoreline were severely damaged. Because of the excellent harbor facilities, it has long been one of the principal ports on the Atlantic coast. There are numerous shops and restaurants along the Newport Harbor waterfront. These are in a low, flat area and many are located on the piers, all susceptible to heavy damages. A recently built hotel and restaurant complex on Goat Island in Newport Harbor could also suffer substantial damages.

Hurricanes - A hurricane is an intense cyclonic storm of tropical origin characterized by low barometric pressures, high winds (75 miles per hour or greater but rarely exceeding 150 miles per hour), heavy clouds and rain, high waves and tidal surges.

The hurricanes that usually affect the eastern coast of the United States from either near the Cape Verde Islands or in the western Carribean Sea. Hurricanes originating near the Cape Verde Islands move westward, usually turn north, frequently crossing the West Indies and then striking the eastern coast of the United States. Hurricanes originating in the Caribbean generally move northward across Cuba, the Gulf Coast and then on to the coast. The most severe hurricanes affecting New England usually arrive from the south-southwest after recurving off Florida and skirting the Middle Atlantic coast.

Characteristic of a hurricane is the torrential rainfall which increases in frequency and intensity as the center approaches. The heaviest rain usually occurs ahead of the eye of the hurricane, providing nearly two inches of rain per hour. For a 24-hour period, total rainfall exceeding 20 inches has been reported. Although a tremendous amount of rain is produced much of the damage associated with hurricanes is caused by the waves generated by the hurricane winds. Waves 45 feet or more in height have been reported at the storm's peak.

Wind velocity in the open ocean influences the height, period, and velocity of the waves produced. The force and duration of the wind determines the ultimate size of the waves. The forward movement of these waves is slowed by friction on the bottom in shoal waters. They rise in height before dissipating or breaking on the shore shelving. Breaking waves, driven by hurricane winds, will run up on a beach or overtop structures well above the wave heights. Reports of wave and flood damage 25 feet above water level are not exceptional. Hurricane waves often do great damage to shorefront real estate and small craft. The hurricane of 1938 carried a number of lighthouses off their foundations which were well above normal water levels in Narragansett Bay. The eye of the hurricane is usually about 15 miles in diameter. Within a circular region extending outward from the eye for 10 to 15 miles are the highest winds of the hurricane. Wind movement of the hurricane approaches the center in a counterclockwise spiral. Consequently, the highest wind velocities occur at points to the right of the center of the hurricane where the spiral wind movement and the movement due to forward motion of the center are in the same direction.

As the center of the hurricane approaches and the velocity of the wind increases the atmospheric pressure decreases rapidly, but the minimum barometric readings do not always occur at the eye. The barometric low is usually 28 inches of mercury about two inches below the normal sea level pressure of 30 inches of mercury.

One of the most devastating effecs of hurricane flooding results from movement of the storm surge onto a shoaling coast and into a bay or inlet. The tidal surge is caused by a combination of hurricane winds and low barometric pressure. The most destructive tidal surge occurs when the peak of the hurricane is synchoronized with the astronomical high tide. Usually the sea rises gradually as the center of the hurricane approaches but it can occur quite quickly resulting in loss of lives and property. The rise in stillwater levels resulting from the combined effects of the offshore surge and local winds may be as much as 12 or 14 feet above the normal high tide in bays and inlets.

There are 4 types of damages resulting from hurricanes; saltwater flooding due to the hurricane surge, riverine flooding from heavy rains, storm driven waves, and high velocity winds.

A long period of heavy precipitation followed by the torrential rains accompanying a hurricane has often generated numerous flash floods.

During the week prior to the September 21, 1938 flood, 4 inches of rain was recorded during the hurricane at Providence. However, 17 inches of rain fell in Connecticut and Massachusetts. If this had been centered over the study area, major river flooding would have occurred in addition to the already destructive tidal flooding. During the hurricane of September 11, 1954, 4.4 inches of precipitation was recorded at Providence and 8.7 inches of rain fell in about 15 hours at the center of the storm, Quonset Point, Rhode Island. This high concentration of rainfall in a short period of time produced serious flooding of many streams. The torrential rains of the hurricane of August 19, 1955 which amounted to over 6 inches in Providence, occurred when the ground was saturated by rain from the hurricane of the previous week.

Flooding from the hurricane surge causes the most destructive and extensive damages. During the hurricane of September 1938, approximately 20,500 acres in Rhode Island and Massachusetts experienced flooding. The 1938 hurricane took over 110 lives and destroyed piers, wharves, yacht clubs, boat houses, thousands of boats and several hundred cottages.

Hurricane Carol in August of 1954 caused 7 to 8 feet of polluted sea water to inundate the dense business district of the city of Providence and left in its wake $92 million in losses from tidal flooding in Narragansett and Mt. Hope Bays. Approximately $30 million in damage to this area was attributed to Hurricane Carol while total losses for the entire city amount to $41 million. The Fox Point Hurricane Barrier completed in

1966 in Providence Harbor, would prevent damages of $46.4 million in the recurrence of a storm of the magnitude of Hurricane Carol. The barrier was constructed in the early 1960's to protect the major portion of Providence from tidal flooding.

Seaside resort areas were particularly hard hit and many exposed beaches were severely eroded. In some areas 50 to 100 feet of developed property were lost. Damages to highways amounted to over $1 million, five bridges were severely damaged and two completely destroyed. Over 400 of the approximately 3,900 homes involved in tidal flooding were completely destroyed.

U.S. Navy installations at North Kingstown and Newport suffered extensive damage in the flood of 1954. Total losses for the town of North Kingstown were in excess of $16 million. Flood damages amounted to $28 million along the western shoreline of the Bay from Narragansett to Cranston where approximately 1,700 homes and cottages sustained damages in 1954. Almost 900 homes were damaged, over 200 leveled in Warwick; most located in the Oakland Beach, Buttonwoods and Conimicut Point Sections. Ninety percent of the industrial losses in Warwick were sustained by just 4 ownerships of which the heaviest losses occurred at the Apponaug Textile Finishing plant. A considerable amount of tidal flooding occurred in Narragansett and South Kingstown, particularly in the Narragansett Pier and Bonnet Shores area. Along the shores of the Pettaquamscutt Rliver estuary, approximately 100 residential structures were damaged. Also substantial property damages were sustained and over 100 pleasure boats destroyed in Pawtuxet Cove.

Along the eastern shoreline of the Bay, plus the Mount Hope Bay area, losses amounted to $23 million. In this area over 2,200 homes were damaged by tidal flooding; 195 of these were totally destroyed. Heaviest damages occurred in the northernmost sections of the Bay area. The most severe damages were inflicted on coastal property in Bristol, Warren and Barrington; also East Providence, which experienced heavy damages at 2 oil refineries. Warren and Bristol are exposed to both Narragansett and Mt. Hope Bays and are therefore especially susceptible to tidal flooding. The Kickemuit Reservoir in Warren was contaminated when sea water poured over the Child Street Dike. Heavy debris in Bristol Harbor caused considerable damages along the shorefront and especially at the Bristol Boat Yard. Towns along the tidal reach of the Taunton River suffering significant tidal flooding were Dighton, Somerset, Berkeley, Freetown and Taunton. Swansea was flooded by both the Bay and the tidal reach of the Lees River resulting in 45 homes being completely destroyed.

The city of Fall River received the heaviest damages of any of the Massachusetts communities. The Firestone Rubber and Latex Products Company on Ferry Street was the hardest hit, sustaining losses of equipment, raw materials and finished products. They have subsequently built floodwalls and gates which provide protection to the 1954 flood level. Since its completion, the entire building complex was destroyed by fire.

Aquidneck Island was struck by hurricane tides in both Narragansett Bay and the Sakonnet River. Consequently there were heavy losses in Middletown, Newport and Portsmouth. Some of the hardest hit sections of the Island were Newport Harbor, Easton Beach, the Cliff Walk, Melville, Island Park and Common Fence Point.

Damage surveys, conducted in the Bay area in 1955 and updated in 1963-1964, were done by means of door-to-door interviews and inspections of residential, commercial, public and industrial properties in the flooded areas. Flood loss information was classified by type of loss and by location as shown in Table 1-18. The loss classifications employed in these surveys were industrial, urban, rural, highway, railroad and utility. In addition losses incurred by tidal flooding can also include such items as parked automobiles, commercial and naval vessels and intangible losses such as lives, health and national security.

Two high and two low tides occur each lunar day in the Narragansett Bay Area. These tides enter the Narragansett and Mount Hope Bays through the east and west passages and the Sakonnet River. The mean range of the tide varies from 3.5 feet at Newport to 4.6 feet at Providence. Spring tides at the same locations have average ranges that vary from 4.4 to 5.5 feet.

Tidal movement is nearly simultaneous throughout the bay; high and low tide for most points occurring within 20 minutes of high and low tides at Newport. The time interval for a complete tidal cycle averages about 12 hours and 25 minutes.

Investigations by the USGS show that the mean sea level along the New England coast has been rising at a rate of approximately 0.02 feet per year since 1930. In the event of a recurrence of a storm of the magnitude of the 1938 or 1954 hurricanes, flood levels nearly 1 foot higher would now occur. The severity of future hurricane tidal flooding will be continually increasing due to this change in mean sea level. There are currently 8 recording tide gages in operation in and around Narragansett Bay. The locations of these gages are Old Saybrook, New London, Groton and Stonington, Connecticut; Mondale, New York, Westerly, Narragansett and Block Island, Rhode Island.

A number of hurricanes and cyclonic storms have reached the coast of southern New England with devastating force while numerous other storms have passed so close that a slight change in meteorologic conditions could have resulted in severe damage. Rhode Island lies in the path of hurricanes moving into New England from the south and therefore has frequently been subjected to tidal floodings from hurricane surges.

The possibility also exists in the lower reaches of the streams that both riverine and tidal flooding could occur simultaneously, producing higher stages than either could individually. For this situation to occur it would be necessary for the tidal surge to occur at approximately the

same time as the peak runoff and the astronomical high tide. Also the greatest rainfall is at the center of the hurricane whereas the highest wind velocities occur to the right of the center due to the counterclockwise spriral movement. For a large runoff to occur in the lower reaches at the time of the tidal surge there would have to be a considerable amount of rainfall immediately prior to the hurricane.

Future Conditions - Projections indicate a population growth of 32 percent between 1970 and 1990. If recent trends continue, agricultural land uses will decrease as urban uses increase. Without careful planning, the loss of wetlands and flood plains will aggravate flooding and storm damage problems, water supply, plant and wildlife habitat and erosion.

Currently available water supply sources will be inadequate to meet 1990 demands. It is currently anticipated that the Providence Water Supply Board will have to extend service to 4 aditional municipalities in the bay area. The proposed Big River Reservoir is expected to be a major additional source of supply by 1990. High quality waters in the Narragansett Bay area will be imperiled as growth continues. High water quality prevails in many portions of the Bay; preservation of existing water quality and construction of facilities to restore water quality to higher standards must be pursued. Currently, almost 75 percent of the area's population use septic systems for wastewater disposal. This situation may change with the occurrence of new growth and development which can be channelled towards proposed sewer service areas in order to make the most efficient use of utilities available.

Narragansett Bay, Rhode Island's greatest natural resource, is a haven for outdoor recreation, fish and wildlife, but existing recreation facilities will not be able to meet the growing recreational demands from this and surrounding areas. Existing beach area will be able to meet about a third of the area's future needs; existing campsites could meet about a third of the total 1990 demands for camping and the existing publicly accessible parks and natural areas will meet more than a third of demands for extensive outdoor recreation. Tourism and recreational demands from the nearby Providence metropolitan area inflate this demand further. Recreation resources of Narragansett Bay will increasingly be pressured by the rapidly growing population within this and adjacent areas.

Existing Plans & Projects - The Fox Point Barrier, a hurricane-flood protection project authorized in 1958, extends across the Providence River immediately south of the Narragansett Electric Company plant and 0.2 miles north of Fox Point. The barrier consists of a concrete gravity dam approximately 700 feet long with connecting dikes extending across the Providence River from Tockwotton Street to Globe Street. Included in the barrier are three river gates and a pumping station. The major portion of the city of Providence is now almost completely protected against hurricane tidal flooding. The Fox Point Barrier provides protection for the

TABLE 1-18

EXPERIENCED 1954 HURRICANE TIDAL FLOOD LOSSES BY TOWN AND TYPE
NARRAGANSETT BAY
MASSACHUSETTS - RHODE ISLAND
(Losses in $1,000)

Town	Urban	Rural	Industrial	Utility	Highway	Railroad	Total
Providence, R.I. (1)	9,610	-	1,000.	-	-	10.	10,620.
Cranston	920.	-	110.	10.	10.	-	1,050.
Warwick	4,890	-	1,720.	70.	20.	40.	6,740.
East Greenwich	320.	-	40.	-	-	-	360.
North Kingstown	16,160.	-	60.	50.	20.	-	16,290.
Narragansett	2,930	-	-	-	50.	-	2,980.
Jamestown	410.	-	-	-	100.	-	510.
E. Providence	2,070	-	550.	30.	120.	-	2,770.
Barrington	1,300	20.	660.	10.	20.	-	2,010.
Warren	850.	10.	160.	120.	-	-	1,140.
Bristol	1,550.	260.	1,070.	30.	140.	-	3,050.
Portsmouth	1,390.	-	-	-	30.	-	1,420.
Middletown	680.	-	-	-	10.	-	690.
Newport	5,150.	20.	80.	200.	-	-	5,450.
Swansea, Mass.	1,080.	-	-	-	-	-	1,080.
Somerset	370.	-	420.	-	20.	-	810.
Dighton	440.	-	340.	-	-	-	780.
Berkley	150.	10.	-	-	-	-	160.
Freetown-Assonet	190.	-	70.	-	-	-	260.
Fall River	910.	-	1,340.	160.	-	-	2,410.
Tiverton, R.I.	750.	-	70.	-	60.	-	880.
Little Compton	160.	-	-	-	10.	-	170.
Bay Total	52,280.	320.	7,690.	680.	610.	50.	61,630.
below Fox Point Providence (2)	20,520	-	5,720	3,300.	410.	690.	30,640.
Grand Total Bay area	72,800.	320.	13,410	3,980	1,020.	740	92,270

(1) Below the Fox Point Hurricane Barrier
(2) Above the Fox Point Hurricane Barrier

NOTE: 1954 Price Levels

commercial and industrial center of the city, extensive transportation facilities, public utilities and many homes. The project was completed and turned over to local interests in 1966.

The Providence River and Harbor is the principal commercial waterway in Rhode Island. The most recent modification of the channel was authorized in 1965 to provide deepening the ship channel to 40 feet, easing channel bends and extending the channel 6.2 miles southward to the southeast side of Prudence Island. Construction began in 1969 and was completed in 1971. A contract for removal of rock and unclassified material was awarded in June 1973. Initiation of work was delayed due to a court injunction relative to environmental concerns. After resolution, work began in August 1975 and the project was completed in January 1976.

The existing Pawtuxet Cove project, authorized in 1962 provides for a channel, 6 feet deep and 100 feet wide, from the Providence River northward behind Washout Point to the head of the Cove at Cranston; an anchorage 6 feet deep and 14 acres in area between the south side of the entrance channel and Warwick Downs State Park; and a 12 foot high protective dike along the east side of the anchorage. This project was completed in 1966.

The 1954 River and Harbor Act authorized provision of an entrance channel at Bullocks Point Cove 8 feet deep and 75 feet wide, a mooring basin 6 feet deep and 8.3 acres in area on the west side of the channel, and an inner channel 6 feet deep and 75 feet wide extending upstream to a turning basin 6 feet deep over an area of 2.9 acres opposite Haines Park. The authorized work completed in 1959 included reconstruction of Bullocks Point to a height of 9 feet above mean low water, with dredged sandfill retained by a rubble-stone dike and jetty. The Bullocks Point Cove was completed in 1959.

The Warren River project, completed in 1887, provided for the removal of a rocky reef situated along the lower two miles of the river below the mouth of the tributary Barrington River. The project also provided for the removal of a large boulder opposite the Warren Lower Waterfront.

The existing project at Warwick Cove, completed in 1966, consists of an entrance channel six feet deep and 150 feet wide, an inner channel six feet deep and 100 feet wide to the head of the cove, and four anchorage areas six feet deep, totaling 13 acres in area.

Apponaug Cove is divided into three areas known as the outer, middle and inner basins. Dredging improvements, in the upper basin, consisting of an access channel to the public landing and four acres of anchorage were completed in 1963.

Adopted in 1890 and completed the following year, the Greenwich Bay project consists of a 10-foot channel extending westward from Long Island to provide access to the Warwick-East Greenwich waterfront along the west side of the cove.

The existing project for the Potowomut River, adopted and completed in 1881, provided for a channel five feet deep through the entrance bar, and for the removal of Eustons Rock at the north side of the channel entrance.

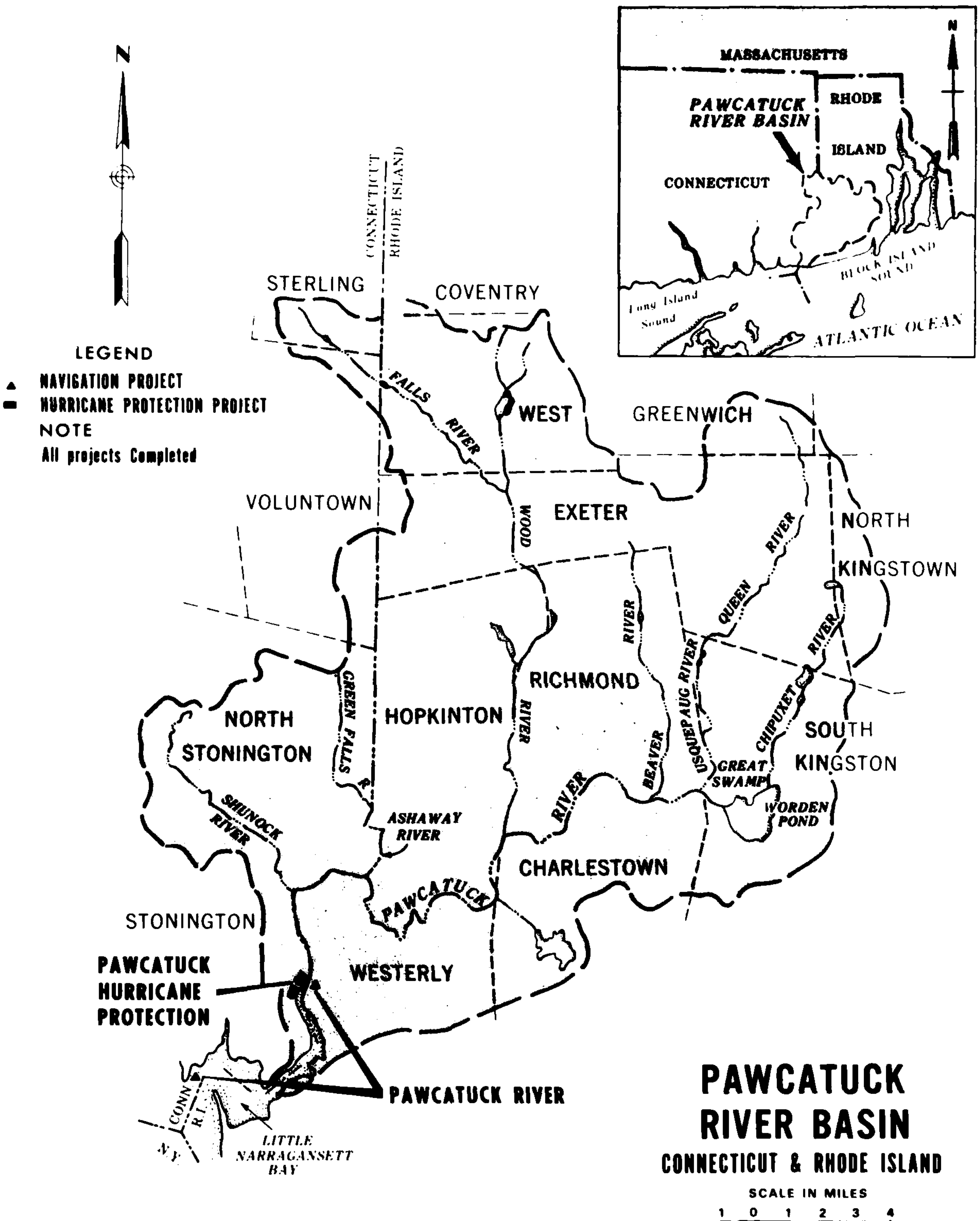
The original project at Wickford Harbor, initiated in 1873 and modified in 1896, provided for removal of boulders and dredging a nine-foot deep channel in the central part of the cove. The more recent project provides for two breakwaters at the entrance to the outer harbor, a channel 12 feet deep and 100 feet wide from Wickford Harbor to Mill Cove, an anchorage adjacent to the channel, and maintenance of the original channel. This work was completed in 1964.

The 1968 River and Harbor Act authorized provision of a breakwater in Bristol Harbor, 1,600 feet long with a top elevation of 10 feet above mean low water, beginning about 400 feet west of the Coast Guard Pier and extending generally in a northwesterly direction. Construction of the project is dependent upon future appropriations and compliance by local interests with the requirements of local cooperation.

The Coasters Harbor project which was completed in 1892 consisted of deepening the head of the channel into the cove at the southeastern end of the island to a depth of 9 feet and cutting additional openings in the causeway at the north side of the cove.

The original project at Newport Harbor was a 15-foot channel from the East Passage of Narragansett Bay around the south end of Goat Island to the inner harbor, a 10-foot anchorage and a 13-foot anchorage, a jetty of the southwest end of Goat Island, partial removal of a sand pit at the south end of Goat Island and construction of jetties along the west shore of the island to reduce erosion. This work was completed in 1906. The existing project consisted of a 21-foot channel around both ends and along the east side of Goat Island, two anchorage areas 13 and 18 feet deep along the main waterfront, and the removal of Nourmahal Rock in Brenton Cove.

Adopted in 1874 and completed in 1915, the original Fall River Harbor project provided for a channel 25 feet deep through Mount Hope Bay to the inner harbor and for an anchorage 25-feet deep adjoining the west side of this channel. The existing project, adopted in 1930 and modified in 1946, 1954, and 1968 provides for a 40-foot channel to the Tiverton shorefront then northerly to the vicinity of the Gulf oil terminal, a 40-foot channel along the Tiverton Lower Pool to the vicinity of the Rhode Island Refining Corporation terminal 40-foot channel from Mount Hope Bay through the eastern part of the Braga Bridge and then northerly to the terminals north



NOTE Delineation of streams on map is limited to major streams

FIGURE 1-1

of the Slades Ferry and Brightman St. Bridges, a 40-foot turning basin above the bridges between the Shell and Montaup Wharves, altering the Brightman St. Bridge, a 30-foot channel in the one mile reach below Slades Ferry Bridge and for maintenance of the original 25-foot anchorage. All work authorized through 1954 was completed in 1959. Preconstruction planning for the 1968 modification, which authorized 40-foot channel depths and bridge modifications, is in progress.

The Sakonnet River project of 1896 provided for channel improvements through the dam opening of the "Stone Bridge." This was completed in 1905. In 1950, following construction of a new highway bridge about one mile northward, the old bridge was removed.

Authorized in 1836, amended in 1899 and 1907, the Sakonnet Harbor project provided for a breakwater extending 400 feet north from the point on the western side of the harbor and for removing to a depth of 8 feet below mean low water the ledge nearest to the breakwater. This work was completed in 1908. Modifications completed in 1957 consisted of construction of a 400-foot extension to the breakwater and dredging the harbor to a depth of 8 feet.

Cliff Walk, a scenic and historical walk along the southeast shore of the city of Newport, traverses privately owned land but is open to the public. The Federal project, authorized in 1965 calls for protective measures including backfill, dumped riprap, stone slope revetment, repairs to existing seawalls and grading and surfacing Cliff Walk for a distance of 18,000 feet. Protective measures along 9,200 feet at the waterfront were completed in September 1972. Due to the lack of local funds the remaining portion is in an "inactive" status.

IMPROVEMENTS DESIRED

PAWCATUCK RIVER BASIN

The State of Rhode Island has acquired the lands necessary for the development of a reservoir on the Wood River in the Pawcatuck River Basin. The Wood River Reservoir, which would be constructed north of the Ten Rod Road in the towns of Exeter and West Greenwich, would be developed as a diversionary impoundment with an estimated yield of 26 million gallons daily to be pumped into the proposed Big River Reservoir in the Pawtuxet River Basin. Present information indicates the need for the Wood River Water Supply Complex. The current construction schedule calls for it to be operable by the year 1995.

The State is also contemplating the use of ground water supplies within the Pawcatuck River Basin. Studies have indicated that the most productive ground water basin in the State of Rhode Island lies in the upper area of the Pawcatuck River Basin.

NARRAGANSETT BAY

Due to public concern following Hurricane "Carol" on 31 August 1954 committees were formed to secure authorization of a hurricane survey (PL 71). This ultimately resulted in construction of the Fox Point Barrier which protects the city of Providence from tidal flooding. Interests in barriers across the three entrances to the Bay for protection of the area below Fox Point has been dwindling in recent years due to the absence of serious hurricanes since 1954.

Massachusetts interests supported the proposed Lower Bay barriers. However residents of the Bay area are concerned about the effects of the barriers on navigation, water quality and pollution, marine life, and recreation within the Bay. Also a key factor in this disapproval was the non-Federal share of the cost. Various Rhode Island interests have proposed alternate means for reduced flooding. These included:

a. Flood Plain Zoning
b. Local Protection by means of walls or breakwaters
c. Temporary or nonpermanent barrier systems
d. Federally supported flood insurance

DEVELOPMENT AND ECONOMY

EARLY DEVELOPMENT

Prior to the arrival of European settlers, Rhode Island was inhabited by five Indian tribes of Algonquin (Algonkian) stock. The Narragansett (Nahiganset) Nation occupied most of the Narragansett Bay area, with the Niantic, Nipmuc, Pequot and Wampanoag tribes located in surrounding areas, principally within Connecticut and Massachusetts. Except for skirmishes with rival tribes, the Narragansetts were peaceful farmers, hunters and fishermen. Historians have documented that European navigators explored the Narragansett Bay area in 1524 (Giovanni da Verrazano, an Italian sailing for France) and 1614 (Adrian Block, Dutch navigator) with the possibility that Miguel de Cartereal (Portuguese navigator) sailed along the entrance to the bay in 1511.

The first European settlement in Rhode Island occurred in 1636 when Roger Williams fled the Massachusetts Bay Colony, in search of increased religious and political freedom, to establish a new colony at Providence (now in Rhode Island). Most of the northern half of the present State of Rhode Island was purchased by Williams from the Narragansett Indians. This area extended generally from Massachusetts on the north to the northern border of Coventry on the south, and from Connecticut on the west to the Blackstone River on the east.

Settlements within other portions of the study area soon followed. Friends of Roger Williams settled an area at the Cranston side of the mouth of the Pawtuxet River known at Pawtuxet Purchase in 1638 as part of the extension of the Providence Colony.

All of the Rhode Island colonies maintained good relations with the Narragansetts until 1675, when the Narragansetts joined forces with Philip (Metacomet), chief of the Wampanoags, who felt that his tribe had received unfair treatment from the Massachusetts Bay and Plymouth colonies. Many white settlers and Indians were killed and towns burned during King Philip's War until Philip suffered a major defeat in the Great Swamp Fight (1675) in King's Towne and was killed the next year near Mount Hope (now Bristol), a village southeast of Providence.

The first settlers in the Massachusetts portion of the Narragansett Bay immigrated during the early 1600's from the already established Plymouth and Massachusetts Bay Colonies. Early settlers in this region were farmers and each community was largely self-sufficient. Bog ore was found along the streambank throughout this region, and iron was manufactured as early as 1656. Iron production was one of the earliest forms of industrialization in the area and it continued to be significant until after the Revolutionary War. Accompanying this early development was the growth of the ship-building, whaling and fishing industries, which continued throughout the 18th century. This activity was concentrated along the shores of Mount Hope Bay in Tiverton and Fall River. A small fishing industry developed in the Cranston-Warwick area, but the seaport of Providence served the commerce needs of that portion of the drainage area, as it does today.

During these early development years, the coastal region offered fertile farming and grazing lands. Slaves frequently worked the fields as a result of the molasses and slave trade that had developed at the nearby Rhode Island ports of Newport and Westerly. All of the scattered villages within the Narragansett basin were principally agricultural communities. Most products were handmade. Early industries included gristmills and sawmills at a few waterpower sites and in the Cranston-Johnston area limited mining of bog iron ore, soapstone and granite. During the early 1800's numerous waterpower sites were developed for the manufacturing of textiles particularly within the communities of the Woonasquatucket River drainage basin. The jewelry-silverware industries also developed around this time with the subsequent development of the fabricated metal industries.

LATER REGIONAL DEVELOPMENT AND URBANIZATION

During the Industrial Revolution the downstream areas of the Woonasqautucket River were settled near available waterpower sites. Attracted by cheap land and the availability of water, wealthy families established textile mills along the river and workers followed the mills into the area. Separate villages grew around each major group of mills and became more or less independent communities. Each set of mills, worked primarily by members of one ethnic group, became the economic center of a community with a distinct ethnic flavor. As employers searched for cheaper labor the British mill workers were displaced first by the Irish, then by French-Canadians, Polish, Italians and most recently

- Portuguese workers. As new workers moved in, distinct ethnic communities were formed. These communities, established through sheer number, developed organizations such as the ethnic church which encouraged a sense of separateness long after the residents spoke a common language and had ceased to be competitors. With the mills offering secure employment, population in the area concentrated around them. This growth of strong local neighborhoods was sufficiently strong in later years to preclude the development of "downtown" or central business centers in the basin communities, except in Providence.

During the period between the Civil War and World War I, the Johnston-Providence villages along the Woonasquatucket River, continued their steady population and economic growth. Although the economy prospered during World War I, the textile industry started to decline during the 1920's because of competition from the many textile firms that had moved to the south. Due to the national depression conditions that prevailed during the 1930's, there was relatively little growth within the basin. The major waves of immigration had ended and limited job opportunities did not encourage migration into the basin.

In the World War II period and the year following, Narragansett Bay was one of the principal naval ports on the Atlantic Coast. The waters of the bay provided the Navy with a natural land locked, deep-water, ice-free harbor for its largest ships. Major activities and installations included the Atlantic Cruiser - Destroyer Force, the Naval War College, and the Naval Underwater Ordinance Station in the lower bay at Newport and Middletown; the Naval Air Station at Quonset and the Construction Batallion Center at Davisville, both in the middle bay in North Kingstown; and the Naval fueling and service facilities at Portsmouth. A complex of berthing areas, docks, and repair facilities situated along the waterfront provided the required shore-based support for these defense activities.

University of Rhode Island's Graduate School of Oceanography (formerly Narragansett Marine Laboratory) forms the nucleus of a Federal-State water oriented research center at Saunderstown in North Kingstown. The Environmental Protection Agency (EPA) has recently completed, at this site, the Northeast Shellfish Sanitation Center, one of three regional laboratories which will serve the country. Other installations planned for this location include a Water Quality Criteria Research Laboratory for the EPA, a Sports Fisheries Laboratory for the U.S. Fish and Wildlife Service and a privately sponsored marine museum and oceanarium. A nuclear reactor was constructed for the Rhode Island Atomic Energy Commission to be used for research purposes. It is estimated that the several components of this complex of marine research facilities, locally known as Narragansett Bay Research Center, when completed will employ about 350 scientists, research assistants, and technicians.

The bulk of population growth in the Pawcatuck River Basin is found in three urban centers, Kingston and Westerly in Rhode Island and Pawcatuck in Connecticut. Kingston, located in the eastern portion of the

basin in the town of South Kingstown, is the site of the University of Rhode Island. Westerly and Pawcatuck, in the southwestern portion of the basin, face each other at the head of a navigation channel on the 5-mile long tidal stretch of the river. The remainder of the population is scattered throughout the basin in fourteen small communities.

Industries in the Pawcatuck River basin include textiles, apparel, printing and electrical equipment, machinery, fabricated metals and granite quarrying. Surplus labor from this area commutes to the New London-Groton area of Connecticut for employment in shipbuilding and other industries. Dairying and truck gardening are the principal agricultural activities within this basin.

A turning point in the regional economy occurred in the early 1940's during World War II when a major economic uplift was experienced, especially in the mills that could be converted to war material production. A shift toward many new industries occurred: electronics, precision instruments, electrical machinery, fabricated metals, plastics and synthetic fibers. In addition, many new jobs were created at large naval installations at nearby North Kingstown (Davisville and Quonset Point) and at the Newport Naval Base. The extension of the State-operated public transit system into the Providence suburbs and the trend toward community by automobile were significant factors in the postwar growth of the upper Rhode Island communities.

Currently, the textile industry remains the single largest employer. The metal trades; consisting of primary and fabricated metals, machinery, and electrical equipment constitute the most important industrial group employing roughly one-third of the State's manufacturing labor force. Other major manufacturing employers include costume jewelry, rubber, and plastics. The diversification which began after World War II has continued as is detailed in Table 1-19.

Although it remains the largest employment category, the last twenty years has been a period of decline in the importance of manufacturing to Rhode Island's economy. Meanwhile Government, trade, finance and services have all experienced an increase in employment. Rhode Island has generally experienced a substantial differential or gap in unemployment as compared with the much lower national average levels of unemployment. As depicted in Figure 1-2, Rhode Island experienced only one boom period since World War II, the period between 1965 and 1970. However, since World War II the State has experienced four major recession periods: 1948-1951, 1953-1955, 1957-1959, and 1974-1976. During the present recession period, the Rhode Island unemployment rate has remained roughly twice the national average. Rhode Island has been a marginal producer, quick to feel the effects of economic downturns and slow to reap the benefits of prosperity. Until recent years, there has been a preponderance of small manufacturing firms with limited resources and growth potentials. Also, Rhode Island has one of the lowest educational attainment levels in the

nation, which has restricted many residents to low paying jobs. The lack of public services (water, sewerage, power and transportation) for much of the acreage zoned for industry, has also been a restricting factor.

The broadening in the economic base of Rhode Island has helped to bring the civilian labor force unemployment level in line with the national average. (The recent divergence can, in part, be attributed to the closing of large naval installations in 1973 and 1974 in Newport and Quonset Point, with the accompanying multiplier effect.)

Although Providence is still the largest city (approximately 180,000 population) and the principal place of employment (approximately 131,000 jobs) within the State of Rhode Island, two conditions have occurred since 1950. One is the outward migration of residents who prefer to live in larger homes on larger lots within the suburbs. The second is the decreasing availability of large blocks of vacant land within the city which negates the expansion of existing industries or development of new industries that usually require sizeable single-floor plants for efficient operation. This second condition was partially offset during the mid-1960's by redevelopment of a rundown warehouse area at the headwaters of Mashapaug or Roger Williams Brook in southwestern Providence into a modern industrial park that is presently occupied by jewelry, footwear, plastics and printing firms.

Population growth figures (1950-1970), for the study area communities and population projections for 1980, 1990 and 2000 are shown in Table 1-20. Excluding Providence which lost population (69,000) between 1950 and 1970, population in the other communities listed in the tables increased from 543,222 in 1950 to 777,609 in 1970, representing a 43 percent increase.

With the exception of the older communities of Central Falls, Pawtucket, and Providence, which lost population, the communities in the study area have experienced a steady population growth.

LAND USE

Between 1960 and 1970, urban land use increased sharply, largely at the expense of previously agricultural lands. Roughly 25 percent of the agricultural lands were lost to urbanization. This shift from agricultural to urban uses during the sixties reflects the large increase in population during that period.

More than half the land in the study area is forested. The majority of the remaining land is utilized for agricultural and residential uses. Land use is detailed in Table 1-21.

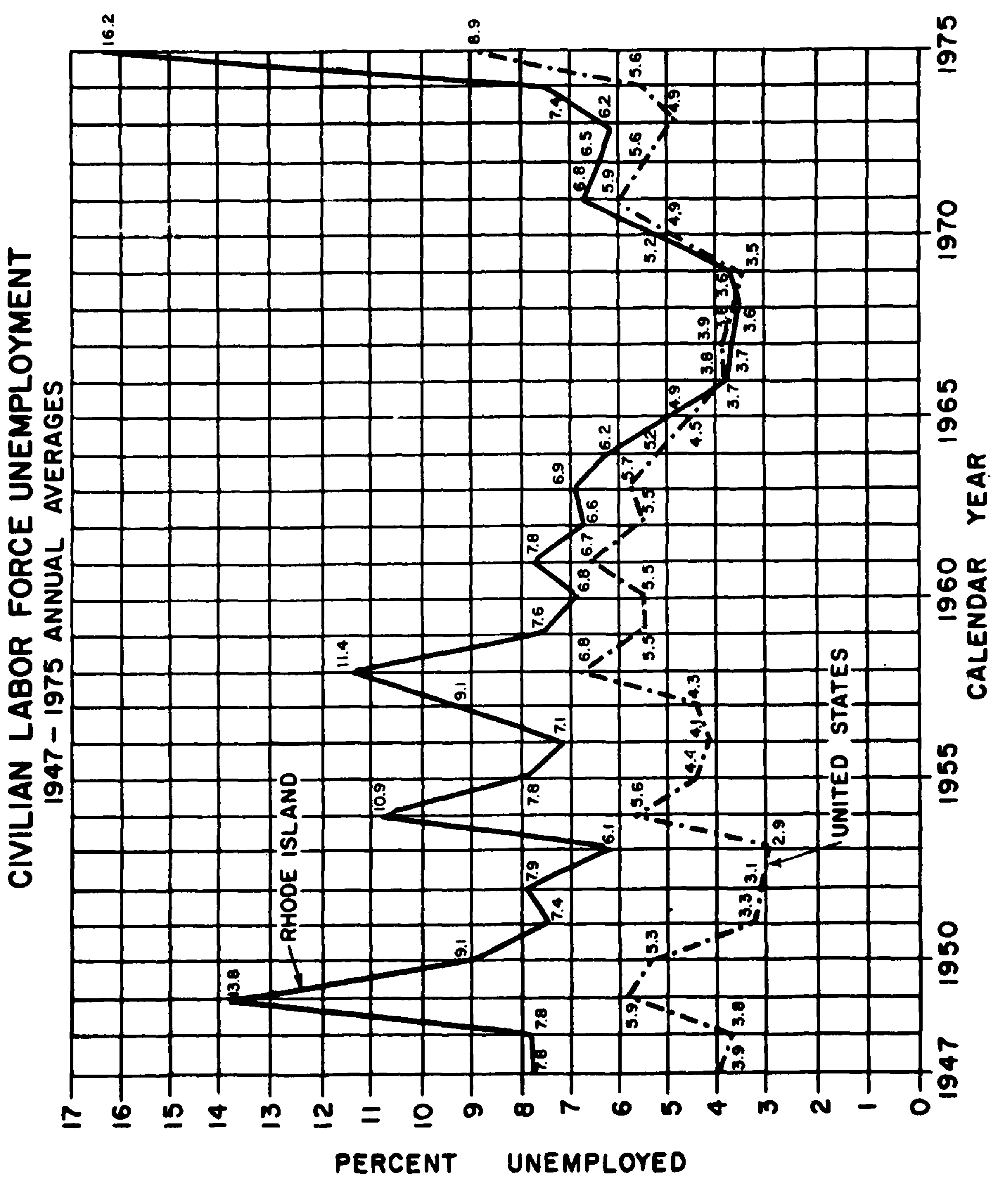

CIVILIAN LABOR FORCE UNEMPLOYMENT
1947 – 1975 ANNUAL AVERAGES
RHODE ISLAND
UNITED STATES
PERCENT UNEMPLOYED
CALENDAR YEAR

Figure 1-2

TABLE 1-19

WOONASQUATUCKET RIVER BASIN
PRINCIPAL EMPLOYMENT WITHIN EACH COMMUNITY

COMMUNITY	EMPLOYMENT CLASSIFICATIONS
Central Falls	Apparel, jewelry and silverware, textiles, trade, service industries, metals and machinery.
Cranston	Government, trade, service industries, jewelry and silverware, chemicals, construction.
Glocester	Government; trade, service industries, transportation, communications and utilities; construction, and agriculture.
Johnston	Trade, jewelry and silverware, government, service industries, fabricated metals, construction.
Lincoln	Service industries, jewelry and silverware, primary metals, trade, government, textiles.
North Providence	Trade, service industry, jewelry and silverware, government.
North Smithfield	Service industries, trade.
Pawtucket	Trade, textiles, service industries, primary metals, government, fabricated metals.
Providence	Service industries, trade, jewelry and silverware; finance, institutions and real estate government; transporation utilities and communications.
Smithfield	Machinery (except electrical), service industries, trade, government, fabricated metals, construction.

TABLE 1-20

COMMUNITY SIZE AND POPULATION GROWTH
IN THE ENTIRE STUDY AREA

COMMUNITY	AREA (SQ. MI.)	PERCENTAGE WITHIN STUDY AREA	1970 DENSITY	1950 POPULATION	1960 POPULATION	1970 POPULATION	1980 POPULATION	1990 POPULATION	2000 POPULATION	AVERAGE ANNUAL GROWTH 1950-1970 (Percent)	AVERAGE ANNUAL GROWTH 1970-1990 (Percent)
RHODE ISLAND											
Barrington	8.6	100.0	2,047	8,200	13,800	17,600	17,600	18,100	18,500	114.6	2.8
Bristol	10.0	98.0	1,790	12,300	14,600	17,900	19,700	21,600	22,100	45.5	20.7
Central Falls	1.3	23.1	14,397	23,550	19,858	18,716	17,600	17,400	17,200	-20.5	-7.0
Charlestown	41.3	62.7	69	1,598	1,966	2,863	4,000	4,500	4,900	79.2	57.2
Cranston	28.6	3.2	2,597	55,060	66,766	74,287	81,200	89,000	93,400	34.9	19.8
East Greenwich	16.7	100.0	575	4,900	6,100	9,600	11,200	12,600	13,600	95.9	31.3
East Providence	13.9	74.8	3,468	35,900	42,000	48,200	54,800	62,300	65,800	34.3	29.3
Exeter	58.2	92.1	56	1,870	2,298	3,245	4,400	4,800	5,000	73.5	47.9
Glocester	55.3	11.0	93	2,682	3,397	5,160	6,700	7,200	7,600	92.4	39.5
Hopkinton	44.0	100.0	123	3,676	4,174	5,396	6,500	7,000	7,600	46.8	29.7
Jamestown	9.4	100.0	309	2,100	2,300	2,900	3,900	3,800	4,000	38.1	31.0
Johnston	23.7	32.9	930	12,725	17,160	22,037	27,500	31,500	33,200	73.2	42.9
Lincoln	19.0	63.2	852	11,270	13,551	16,182	18,100	19,200	20,300	43.6	18.7
Little Compton	21.8	33.5	110	1,600	1,700	2,400	3,300	4,000	4,300	50.0	66.7
Middletown	12.7	100.0		7,400	12,700		16,600	18,300	20,000		
Narragansett	14.1	61.7	504	2,300	3,400	7,100	10,000	10,800	11,600	208.7	52.1
Newport	7.6	100.0	4,553	37,600	47,100	34,600	31,000	33,000	34,000	-8.0	-4.6
North Kingston	43.4	43.3	867	14,800	19,600	29,800	25,300	40,000	47,900	101.4	34.2
North Providence	5.8	100.0	4,196	13,927	18,220	24,337	28,800	31,700	34,200	74.7	30.3
North Smithfield	25.1	17.5	372	5,726	7,632	9,349	11,000	12,000	13,400	63.3	28.4
Pawtucket	8.8	38.6	8,748	81,436	81,001	76,984	75,000	76,500	76,800	-5.5	-0.6
Portsmouth	23.4	100.0	534	6,600	8,300	12,500	13,700	15,000	16,300	89.4	20.0
Providence	18.1	85.6	9,896	248,674	207,498	179,116	170,100	177,500	196,000	-28.0	-0.9
Richmond	40.6	100.0	65	1,772	1,986	2,625	3,600	4,000	4,400	48.1	52.4
Smithfield	27.8	93.2	485	6,690	9,442	13,468	15,500	17,500	19,500	101.3	29.9
South Kingston	62.5	48.5	271	10,148	11,942	16,913	21,600	23,000	24,700	66.7	36.0
Tiverton	36.1	47.9	349	5,700	9,500	12,600	14,200	15,400	16,800	121.1	22.2
Warren	5.8	51.7	1,810	8,500	8,800	10,500	11,100	12,300	13,900	23.5	17.1
Warwick	34.9	43.0	2,398	43,000	68,500	83,700	93,600	103,600	117,700	94.7	23.8
West Greenwich	50.6	53.4	36	847	1,169	1,841	2,800	3,200	3,000	117.4	73.8
Westerly	33.0	73.3	523	12,380	14,267	17,248	19,000	21,100	23,000	39.3	22.3
CONNECTICUT											
North Stonington	56.3	66.8	67	1,367	1,982	3,748	4,400	4,700	5,000		
MASSACHUSETTS											
Attleboro	27.9	3.6									
Dighton	26.0	16.9									
Fall River	22.9	8.3									
Rehoboth	47.7	92.7									
Somerset	28.5	17.2									
Swansea	16.8	100.0									

TABLE 1-21

LAND USE 1971[1]
(PER CENT)

	WATER	AGRICULTURE	OPEN WETLAND	FORESTED WETLAND	DRY FORESTED	MINING & WASTE DISPOSAL	OUTDOOR RECREATION	INDUSTRIAL	COMMERCIAL	RESIDENTIAL	TRANSPORTATION	OPEN & PUBLIC
PAWCATUCK RIVER												
Charlestown, RI	11.3	6.9	3.1	11.7	57.4	0.4	0.9	0.1	0.2	5.9	1.5	0.4
Coventry	5.0	7.8	1.6	0.0	74.0	0.7	0.4	0.4	0.4	8.7	0.2	0.8
East Greenwich	1.0	12.2	1.1	0.0	60.4	1.0	1.6	0.6	1.5	16.2	1.4	3.2
Exeter	1.3	8.4	1.1	6.0	79.7	0.1	0.5	0.0	0.1	2.4	0.0	0.4
Hopkinton	3.1	10.9	1.9	10.2	66.1	0.1	0.2	0.2	0.2	6.1	0.8	0.2
North Kingston	1.9	17.5	2.8	0.0	45.9	1.1	2.1	0.5	1.1	14.6	4.3	8.1
Richmond	1.4	12.2	3.1	7.5	70.3	0.3	0.6	0.1	0.1	3.9	0.2	0.3
South Kingston	10.5	18.4	4.3	9.4	42.2	0.8	1.0	0.2	0.4	10.5	1.0	1.4
Westerly	7.8	12.8	4.5	22.7	29.2	1.3	2.8	0.5	1.0	15.8	0.7	0.8
West Greenwich	1.6	4.7	1.3	3.1	84.4	1.2	0.1	0.0	0.0	2.3	0.6	0.5
TOTAL	4.8	11.0	2.5	6.8	62.5	0.7	0.9	0.2	0.4	7.8	1.0	1.5
WOONASQUATUCKET RIVER												
Central Falls	5.8	0.0	3.1	0.0	4.6	0.5	1.9	12.2	11.8	51.1	2.8	6.3
Cranston	2.0	20.2	2.9	0.0	29.0	1.0	1.6	1.9	3.3	27.4	4.4	6.4
Glocester	4.1	7.0	1.0	0.2	82.7	0.3	0.2	0.1	0.2	4.0	0.0	0.3
Johnston	3.1	9.4	3.5	0.0	60.8	1.7	0.4	0.7	1.3	16.1	1.7	1.2
Lincoln	2.6	14.9	1.9	1.0	52.8	0.7	3.5	2.4	0.2	14.9	2.6	2.4
North Providence	2.2	11.7	1.2	0.0	19.3	0.4	4.0	1.5	4.4	48.0	0.8	7.1
North Smithfield	3.0	13.6	1.5	1.9	65.9	1.7	0.2	1.1	0.4	8.6	1.0	1.0
Pawtucket	2.9	1.1	1.0	0.0	5.8	0.4	5.2	11.6	5.6	51.3	4.2	10.9
Providence	6.3	1.0	0.2	0.0	4.3	0.2	5.3	7.1	11.1	43.0	9.5	12.0
Smithfield	4.9	12.9	1.7	6.1	58.4	1.6	0.3	0.7	0.8	9.9	2.0	0.8
TOTAL	3.7	10.5	1.7	1.1	52.8	0.9	1.5	2.0	2.2	17.7	2.5	3.3
NARRAGANSETT BAY												
Dighton, MA	2.2	18.7	2.0	2.6	63.6	0.7	1.0	0.6	0.4	7.5	0.0	0.7
Rehoboth	0.7	17.9	2.4	9.6	58.7	0.6	2.3	0.1	0.2	6.8	0.3	0.4
Seekonk	0.6	24.5	3.0	10.8	31.9	1.3	4.1	0.4	1.2	16.8	1.8	3.7
Somerset	19.6	17.0	2.2	0.0	13.7	0.6	2.1	4.4	2.6	33.0	1.7	3.1
Swansea	3.7	23.8	2.1	12.1	35.0	0.8	2.2	0.3	0.7	14.6	2.4	2.2
Barrington, RI	17.7	8.5	9.4	1.7	17.5	0.3	4.0	0.2	0.7	36.2	0.8	2.9
Bristol	5.6	26.2	3.7	0.0	30.1	1.1	2.7	1.9	1.1	23.6	0.2	3.9
Coventry	5.0	7.8	1.6	0.0	74.0	0.7	0.4	0.4	0.4	8.7	0.2	0.8
Cranston	2.0	20.2	2.9	0.0	29.0	1.0	1.6	1.9	3.3	27.4	4.4	6.4
E. Greenwich	1.0	12.2	1.1	6.9	53.4	1.0	1.6	0.6	1.5	16.2	1.4	3.2
E. Providence	6.3	6.9	2.1	4.0	14.4	1.5	7.2	5.2	4.2	33.9	7.2	7.1
Exeter	1.3	8.4	1.1	0.0	85.7	0.1	0.5	0.0	0.1	2.4	0.0	0.4
Jamestown	0.9	28.3	3.9	0.0	32.4	0.4	2.3	0.0	0.2	22.6	0.6	8.3
Little Compton	7.9	33.0	1.5	15.0	33.0	0.1	0.8	0.0	0.1	8.6	0.0	0.1
Middletown	2.9	49.8	6.1	0.2	3.8	0.3	3.4	0.0	2.0	22.7	2.1	6.9
Narragansett	14.4	12.2	5.5	0.0	33.4	0.1	3.5	0.1	0.9	24.5	1.2	4.2
Newport	6.8	8.1	2.9	2.8	5.6	0.6	6.1	0.3	3.3	45.4	4.7	13.3
North Kingston	1.9	17.5	2.8	5.6	40.3	1.1	2.1	0.5	1.1	14.6	4.3	8.1
Pawtucket	2.9	1.1	1.0	0.0	5.8	0.4	5.2	11.6	5.6	51.3	4.2	10.9
Portsmouth	2.5	38.5	4.5	0.0	25.1	0.7	3.4	1.3	0.5	15.3	2.3	5.7
Providence	6.3	1.0	0.2	0.0	4.3	0.2	5.3	7.1	11.1	43.0	9.5	12.0
S. Kingston	10.5	18.4	4.3	0.0	51.6	0.8	1.0	0.2	0.4	10.5	1.0	1.4
Tiverton	4.9	18.9	1.8	8.9	51.5	0.9	0.1	0.1	0.4	10.6	1.3	0.6
Warren	17.8	26.8	8.5	0.0	21.5	0.0	1.0	1.2	2.2	18.6	0.5	1.9
Warwick	6.3	9.2	2.2	0.0	23.2	0.9	4.2	1.5	3.9	36.6	6.5	5.5
W. Greenwich	1.6	4.7	1.3	0.0	87.5	1.2	0.1	0.0	0.0	2.3	0.6	0.5
W. Warwick	3.1	12.9	1.0	0.0	31.3	0.6	2.7	2.9	4.1	35.9	1.5	4.1
TOTAL	4.8	16.0	2.6	3.0	47.4	0.7	2.0	1.0	1.4	16.0	1.9	3.2

1. Source: MacConnell Studies and SENE Study

APPENDIX 2
PLAN FORMULATION

APPENDIX 2: PLAN FORMULATION

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ASSESSMENT AND EVALUATION OF POTENTIAL SOLUTIONS

This section investigates the advisability of potential solutions for issues in the water resource areas discussed in the preceding section. Existing water related problems within the Pawcatuck River Basin, Woonasquatucket River Basin, and Narragansett Bay Local Drainage Area require consideration of flood management measures, phased development of public water supply and water quality improvement measures. Alternative solutions for satisfying the flood control needs are evaluated in this text. Water supply and water quality related improvements measures have been the subject of previous and ongoing studies by the Urban Studies Branch of the Corps of Engineers, the Rhode Island Water Resources Board and the Rhode Island Statewide Planning Program, respectively.

There are many possible regulatory and corrective measures for meeting flood protection needs. This section shall outline economic and technical criteria, environmental and social considerations and the various potential measures considered within the context of this report. Only appropriate measures related to the specific needs of each of the three individual study areas were evaluated at more than a cursory level.

FORMULATION AND EVALUATION CRITERIA

The selected plan must represent an acceptable and justified solution that best resonds to the problems and needs of the area. Technical, economic and social criteria were applied in evaluating all the possible alternatives as well as any potential environmental degradation that could occur because of the projects implementation.

Abbreviated planning methods were used for determining the most viable alternatives. They are explained more fully in the following paragraphs of this section. It should be emphasized that for all alternatives considered supplemental planning criteria involving public acceptability, project completeness, its effectiveness, any possible irreversible effects, and the ease of maintenance and operation were used to refine the number of alternatives to a tolerable number without obviating the problems and needs of the study area.

Socioeconomic data used in evaluating the benefits and costs of the various alternatives considered were derived from Corps investigations and other basic economic data published by other Federal and State agencies. Hydrologic and hydraulic data obtained from Corps investigations and from the Department of Agriculture, Soil Conservation Service. Environmental assessment information was obtained from Corps studies and from the Rhode Island Statewide Planning Program and Rhode Island Department of Health.

Economic Criteria

General economic criteria applied in the evaluation of alternatives are summarized as follows:

a. Tangible benefits must exceed project economic costs.

b. Scope of development should provide maximum net benefit, however, intangible considerations, such as risk to lives and property could result in a project size which is greater than that which would produce maximum net benefits.

c. There are no more economical means, evaluated on a comparable basis, for accomplishing the same purpose or purposes which would be precluded from development if the recommended plan were undertaken. This limitation refers only to alternative possibilities that would be physically displaced or economically precluded from development if the recommended plan were implemented.

Technical Criteria

Technical criteria were adopted from appropriate engineering regulations, manuals, pamphlets and technical letters and supplemented by engineering judgment and technical experience. Where practicable, the alternative measures considered for urban areas were formulated in accordance with applicable regulations which stipulates that the standard project flood is an appropriate level of protection for high dikes and floodwalls in urban areas. It also states that if the standard project flood protection plan is unjustified or only marginally justified, the level of protection may be reduced to yield a more economically feasible plan by utilizing alternative flood damage reduction measures. However, reductions in the level of protection below the standard project flood are to be avoided whenever possible.

Environmental and Social Considerations

Environmental and social criteria utilized in considering the Environmental Quality objective, and the Social Well-Being and Regional Development accounts should include the following requirements of the National Environmental Policy Act of 1969 (Public Law 91-190):

a. Analysis of the environmental impact of any proposed action.

b. Identification of any adverse environmental effects which could be avoided should the proposal be implemented.

c. Evaluation of alternatives to the proposed action.

d. Determination of the relationship between local short term uses of man's environment and the maintenance and enhancement of long term productivity.

e. Accounting of any irreversible and irretrievable commitments of natural resources and biological systems which would be involved in the proposed action whould it be implemented.

In order to attain the environmental objectives as specified in the Principles and Standards, the following factors should also be considered:

a. Management, protection, enhancement or creation of areas of natural beauty and human enjoyment.

b. Management, preservation or enhancement or especially valuable or outstanding archeological, historical, biological and geological resources and ecological systems.

c. Enhancement of quality aspects of water, land and air, while recognizing and planning for the need to harmonize conservation of the resources with the land use objectives of productivity for economic use and development.

d. Development and use objectives which minimize or preclude the possibility of undesirable and irreversible changes in the natural environment.

As mandated by Section 122 of the River and Harbor Act of 1970, adverse economic, social and environmental effects of proposed projects should also receive full consideration and will include the following:

a. Effects of air quality, noise levels and water pollution.

b. Destruction or disruption of manmade and natural resources, aesthetic values, community cohesion, and the availbility of public facilities and services.

c. Adverse employment effects and tax and property value losses.

d. Injurious displacement of people and businesses.

e. Disruption of desirable community and regional growth.

f. Public acceptance of proposed improvements and ability and willingness to meet local cooperation requirements.

Social well-being factors are other desirable elements that should be included in the study and should include the following:

a. Possible loss of life and hazards to health and safety of the people with and without project conditions.

b. Preservation of pleasing aesthetic values and other desirable environmental effects, such as pleasing landscapes.

These environmental and social factors form the basis for evaluating and formulating alternative measures for the study area.

In formulating alternative measures an array of regulatory and corrective measures as well as a No Action program were considered. These measures were compared against the base condition using the criteria of economic efficiency, environmental enhancement and social well-being and were evaluated as acting either independently or supplementing one another. These measures are listed in Table 2-1. Subsequent paragraphs briefly describe each measure and the rationale used during the screening processes. Detailed descriptions are provided in the main report for those measures which passes preliminary screening and were further evaluated.

NO ACTION PROGRAM

In the recent several decades significant development has occurred within the flood plains. Additional limited flood plain land will be built on until the existing Federal, State and local regulations are fully enforced. The No Action Program assumes that in the absence of any corrective Federal Program, local interests would elect to participate in the National Flood Insurance Program (NFIP) and enforce its requirements to control the future growth within the flood plains.

By declining to participate in the NFIP, communities become ineligible for any Federal funds to be expended within a flood prone development. As ownerships of existing properties in the flood plain are transferred, new homeowners desiring financing from any Federally insured lending institution must obtain flood insurance. By law, if this necessary insurance coverage cannot be obtained, a mortgage will not be underwritten.

The No Action Program is a measure that already has been adopted by some of the basin communities. As soon as the remaining towns enter the regular program of the NFIP, the No Action Plan will be completed. This program, at a minimum, would allow the flood plain property owner or a tenant the opportunity to purchase subsidized insurance coverage to help protect against any economic losses that could occur as a result of a major flood event.

REGULATORY MEASURES

By themselves regulatory measures do not reduce, eliminate or prevent the threat of flooding. They regulate or discourage the use and development of the flood plains, lessening the threat of flood damage and possible loss of life. Several regulatory measures which are nonstructurally oriented and applicable to this watershed are described in the following paragraphs.

<u>TABLE 2-1</u>

POTENTIAL MEASURES

NO ACTION PROGRAM

(See Text for Definition)

REGULATORY MEASURES

1. National Flood Insurance Program

2. Flood Plain Regulations
   a. Encroachment Lines
   b. Zoning
   c. Subdivision Regulations

3. Land Use Programs

4. Other Regulatory Measures
   a. Building Codes
   b. Urban Redevelopment
   c. Tax Adjustments
   d. Warning Signs
   e. Health and Fire Regulations
   f. Cleanup Campaign
   g. Flood Forecasting

CORRECTIVE MEASURES

1. Land Treatment Measures

2. Reservoirs

3. Walls and Dikes

4. Reservoir Management Programs

5. Hurricane Barriers

6. Stream Improvements
   a. Channel Modification
   b. Modification or Removal of Dams
   c. Diversion of Floodflows

7. Floodproofing or Relocation

National Flood Insurance Program - This program was established under the Housing and Urban Development Act of 1968, expanded in the Flood Disaster Protection Act of 1973 and subsequently amended. It was specifically designed to provide limited amounts of flood insurance, previously unavailable from private insurers, to property owners by means of a Federal subsidy. In return for this subsidy, the Act requires that State and local governments adopt and enforce land use and control measures that will restrict future development in flood prone areas in order to avoid or reduce future flood damages. These measures include flood plain zoning, careful siting and drainage preparations, special construction practices and building materials, special treatment of sewage disposal systems, and elevation of the first floor above the level of the 100-year flood. Flood insurance is available through local insurance agents only after a community applies and is declared eligible by the Flood Insurance Administration, US Department of Housing and Urban Development (HUD)

Flood Plain Regulations - Several decades of flood plain regulatory experience at State and local levels, plus a substantial body of favorable court cases, attest to the important role flood plain regulations can play in preventing future increases in flood problems. Implementation of adequate regulations may prohibit new uses in urban and rural floodway areas that may cause damaging increases in flood heights. They may require that new uses in both urban and rural flood areas be designed with individual flood protection through elevation on fill or structural floodproofing to the 100-year flood elevation.

These are three principal flood plain regulatory tools at the local level that are available for usage. These consist of zoning, subdivision controls and building codes, each of which is detailed in the following paragraphs and summarized in Tables 2-2 through 2-4.

a. Zoning - Zoning is the most popular flood plain management. Traditional zoning divides a community into districts and applies varying use standards to each of the districts. A zoning ordinance consists of a map which delineates the use districts and a written text which describes use standards for the districts. Use standards are of two types, one that determines the classes of use (commercial, residential, etc.) in the district and the second that establishes minimum standards from permitted uses, such as lot size and building setbacks.

Flood plain zoning maps and the accompanying text are often part of a broader zoning ordinance. One or more flood plain districts are usually delineated on the community zoning map. A single district approach tightly controls all development within the delineated areas. Its use is acceptable for rural towns where considerable vacant land exists in a nonflood plain area. A second approach involves the delineation of two districts; a floodway and flood fringe area. Development is tightly controlled in the floodway to preserve floodflow capacities, but a wide range of uses is generally permitted in the flood fringe as long as each

individual structure is protected against flooding losses at the hundred year event. This two district approach permits a wider range of flood plain losses.

The floodway is a portion of the area a selected flood (100 year for the purposes of this report and to coinide with the NFIP definitions) would occupy consisting of a stream channel and overbank areas. The floodway is calculated to be capable of conveying the selected flood discharge without flood heights or velocities increasing to exceed stated levels (1-foot for this report and NFIP). The regulatory flooding is not an actual channel or concrete conduit, rather an area of sufficient width and flood conveyance characteristics to pass the floodwaters from upstream to downstream points along a watercourse without increasing the flood heights. In this calculation all areas outside of the floodway are assumed to play no role in passing floodflows, and the floodway itself is assumed to remain in an open condition. Floodway areas are subject to frequent high velocity flooding often at considerable depths. The flood fringe is the portion of the regulatory flood plain beyond the limits of the floodway. It is subject to less frequent and lower velocity flooding and does not play a major role in passing floodflows. See Figure 2-1 for a graphical view of each definition.

b. Subdivision Regulations - Subdivision regulations control the division and sale of lands. The regulations require that landowners prepare detailed maps or "plates" prior to the sale of lots. Plates must first be approved by the planning commission. Plates must comply with standards established in the subdivision regulations, zoning and other laws. Subdivision standards related to flooding typically require that lots be made suitable for the intended uses, and that the subdivider install public facilities such as roads, sewers and water with partial or total protection from flooding.

c. Building and Housing Codes - These simply regulate the building design and construction materials. Building areas and a variety of special codes have been adopted by some communities to reduce flood problems or assist in the construction of flood control works. Codes are subject to the same general legal requirements as zoning and subdivision controls. They address limited aspects of flood plains use and a small number of uses and are therefore less susceptible to challenge as a taking of property. However, when exercised in isolation they are also less useful in carrying out overall flood plain management goals.

Flood Warning Systems - The National Weather Service (NWS) is responsible for forecasting flash floods (those which crest within a period of six hours) and major flood (those which take a longer period to crest). Flood forecasts are generally based upon the amount of precipitation and/or snowmelt occurring within a river basin. Flood warning systems utilize sirens, radio, television, and newspapers to disseminate information on floods.

Table 2-2

OVERVIEW: FLOOD PLAIN ZONING

Purposes	Regulatory Standards	Advantages	Limitations
1. Protect public safety and prevent nuisances by prohibiting dangerous uses (e.g., chemical factories in flood hazard areas), unreasonable increases in flood heights due to floodway encroachments, and threats to safety by location of quasi-public uses such as motels in flash-flood areas.	1. Delineate floodway areas and prohibit new structural uses and land alterations which will individually or cumulatively increase flood heights or velocities beyond defined levels.	1. The major tool of comprehensive planning to promote the most suitable use of lands throughout a community.	1. May "take" private property if too restrictive.
2. Promote most suitable and economic use of community lands as a whole by implementing comprehensive land use plans allocating flood plain areas to uses consistent with the flooding threat.	2. Establish flood protection elevations and protection standards for floodway and flood fringe areas and uses.	2. Can incorporate wide range of provisions relating to flood plain management and other objectives.	2. Does not regulate sale or transfer of lands.
3. Reduce the cost of public facilities and assist in the implementation of facility plans for roads, sewer, water, schools, etc. by preventing or limiting the type and density of development in flood hazard areas.	3. In some instances, abate existing floodway uses of a nuisance nature and require floodproofing with major alteration of flood fringe uses.	3. Can separate flood areas into zones depending upon flood hazard and apply varying standards to the zones.	3. Often weakened by irrational variances and exceptions.
	4. Divide flood fringe into commercial, residential and industrial flood fringe zones, and other districts with specifications designed to reduce conflicts between uses and promote the general welfare.	4. Most useful tool in preserving floodway areas.	4. Is largely prospective in nature (applies only to new uses) and usually unsuccessful when applied to high-value, nonnuisance existing uses.
		5. Can be applied (in some areas) to existing uses with a nuisance character.	5. Usually does not incorporate detailed building design standards.
			6. Many states require prior comprehensive, community-wide planning although this requirement has not been strictly enfcrced.

Table 2-3

OVERVIEW: FLOOD PLAIN SUBDIVISION REGULATION

Purposes	Regulatory Standards	Advantages	Limitations
1. Prevent victimization and fraud due to sale of flood lands to innocent purchaser.	1. Prevent subdivision of land unsiutable for intended purposes.	1. In many states, may be made to apply extraterrirorially for urbanizing areas.	1. Only indirectly controls use of land; must be in combination with zoning.
2. Protect floodway areas from encroachment by roads, buildings, etc.	2. Require that each building site have an area above flood elevation suitable for building purposes, onsite waste disposal (where applicable) and adequate access.	2. Very flexible in negotiating with developer.	2. Difficult to protect floodways unless they are identified on maps.
3. Insure that roads, sewers, water supply, and other subdivision services are located in areas above flood elevations or protected against flooding.	3. Require that flood hazard areas be noted on face of plat, and in some cases, the adoption of deed restrictions to control future uses in flood-prone areas.	3. In most states, does not require prior comprehensive planning although a street plan is often required.	3. Does not apply to structural design or materials for future structures on subdivision land.
4. Implement master and comprehensive plans including public facility components.	4. Require flood protection for sewer, water, and roads installed by subdivider.	4. Can be used to require developer to provide flood data on a case-by-case basis.	4. Applies, in many instances, only to new land sales and divisions.
5. Insure that subdivider installs drainage facilities which are consistent with community drainage system standards.	5. Require installation of drainage facilities or payment of fees in lieu of installation by subdivider.	5. Not as vulnerable to judicial attack as zoning.	5. "Loopholes" common in ordinances which permit subdividers to escape enforcement through "strawman" transactions (i.e., multiple divisions through friends, relatives).
	6. In some instances, require dedication of flood areas as parks or for other open space purposes by the subdivider.		

Table 2-4

OVERVIEW: FLOOD PLAIN BUILDING CODES

Purposes	Regulatory Standards	Advantages	Limitations
1. Protect public and private safety from structures which may collapse during flood.	1. Require elevation of structures and utilities on fill, pilings, or by other means.	1. Applies to new structures.	1. Applies only to new uses.
2. Prevent nuisances from floating structures which may jam bridges, litter other lands, and add to the destructive force of flood flows.	2. Alternatively, require structural floodproofing of buildings and utilities through special design and use of waterproof materials.	2. Often sustained in court.	2. Performance standard approaches require expertise in administration
3. Protect public facilities.		3. Can be adopted by reference in most states.	3. Do not usually apply extraterrirorially.
4. Prevent blighting, reduction in property values, decrease in tax revenues.		4. Simple adoption procedures.	4. Must be used in combination with other tools to preserve floodway.
5. Protect buildings and contents from flood damage.			5. Often not properly enforced.
			6. Detailed flood elevation data essential for operation of regulations. Flood velocities, flood duration, wave action, erosion problems and other types of "site specific" data required to design or evaluate proposals for structural flood-proofing.

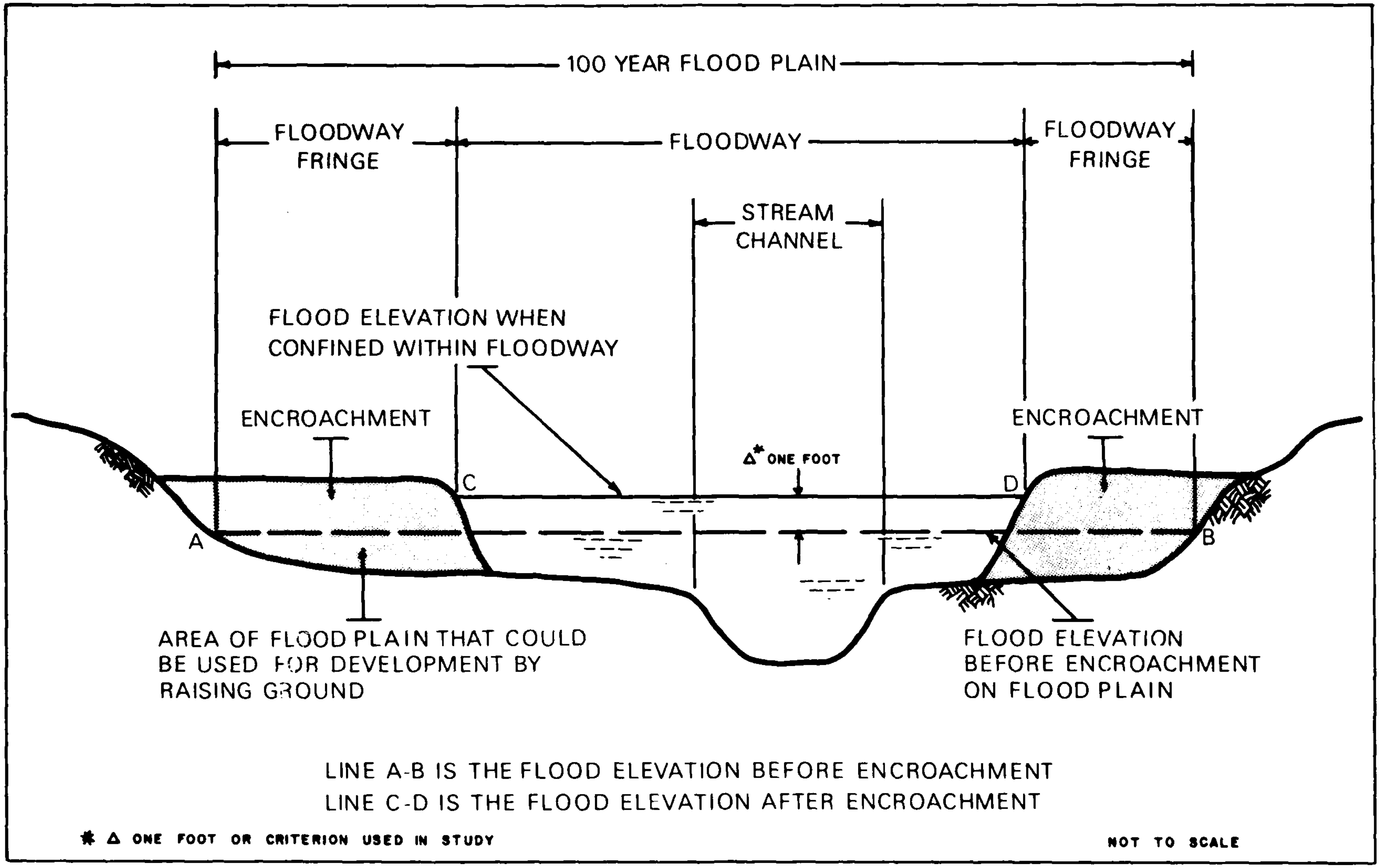


Fig. 2-1

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
Federal Insurance Administration

FLOODWAY SCHEMATIC

A few communities have adopted flash flood alarm systems which automatically activate an alarm when floodwaters reach a certain level.

Of course, the determination of a flood hazard is only one aspect of a flood warning system. The other aspect - dissemination of information concerning the hazard - is often more difficult. Television and telephones have somewhat simplified the task, but serious communicatin problems still exist for sudden flood events.

To be optimally useful, flood warnings must allow sufficient time for the evacuation of the people and goods from the flood plains or the initiation of emergency flood protection measures. Floodgates and movable doors for floodproofing may be inoperable due to lack of maintenances or repair, or they may have been misplaced. Cars may not be able to be removed from dealer lots. Material or stock and contents may not be able to be elevated to high ground. It is therefore important that logistic support be provided to make use of advance warnings.

Urban Renewal - Urban renewal has been used in some instances to renovate, raze or rebuild some flood-prone areas and to allocate the lands to open space use to reduce flood losses, provide open space, reduce disease and serve other community objectives.

Tax Incentive - Tax incentives have, in some instances been used to encourage preservation of the flood plain in an open condition to reduce flood losses, provide open space, preserve agricultural land and meet other objectives.

Public Open Space Acquisition - The acquisition of flood plain areas for public open space use has grown rapidly in popularity. Some cities such as Milwaukee have purchased virtually all flood plain areas for park and parkway use. Such acquisitions may serve the final functions of controlling private development and providing public open space for parks, wildlife areas, hiking, water sports and similar use. Public open space recreational uses often may be designed with minimum damage potential from floodwaters.

While flood plain lands may be less costly for park acquisition than similar lands throughout a community due to the flooding threats acquisition costs often exceed several thousand dollars per acre. For this reason, easement rather than fee purchase may be attractive. However, experience with scenic, conservation, and similar types of easements may sometimes be expensive and are unsatisfactory where the public must make intensive use of private land for picnicking or other uses.

Federal grant-in-aid for park acquisition are available from the Land and Water Conservation Fund of the Heritage Conservation and Recreation Service, previously Bureau of Outdoor Recreation. In addition, revenue sharing and State open space funding programs are available in many

states. Generally, the total Federal share may not exceed 50 percent of acquisition costs although State grants-in-aid may increase the total State and Federal contribution. In some states, park acquisition for flood plain lands is given high priority because of the multiple benefits involved. However, flood plains do not in all instances make good parks because of their topographic features or inaccessibility to users.

Proposals have been made to subsidize local flood plain acquisition for open space purposes through State or Federal grant-in-aid. Such Federal or State subsidies to accomplish multiple goals might in some instances be favored in comparison with flood control works because the multiple benefits (recreation, flood loss reduction) accrue directly to public (rather than private) uses.

CORRECTIVE MEASURES

In urbanized flood-prone areas, the most cost effective way to reduce existing flood losses is with corrective measures. When considering several flood-prone city blocks of stores and homes, or a large industrial center, it is unrealistic to expect that the regulatory measures will completely solve flood problems.

These corrective measures listed below are the traditional measures that deal with flood problems. Modifications of the natural flood regime are designed to change the extent and timing of floodflow, to lower elevations and to partially or wholly protect individual structures or entire areas from flooding. Each technique has a somewhat different function and application.

Land Treatment Measures - Substantial portions of the upper study area have undergone a land use change from agriculture to residential or other urban types. As this practice is expected to continue, vegetative and mechanical land treatment measures could be an effective tool in helping to control erosion. In addition to damaging the lands from which the soil originally came, erosion greatly increases the sediment transport rate of the stream resulting in high deposition and increased scour rates. It is therefore necessary to try to control erosion in these developing areas. Proper grading of the new subdivisions along with the preservation of as many trees and shrubs as possible is essential. Where possible fast growing annual grass seed should be used intermixed with the slow growing perennial species, to help establish a good cover to soil. Maximum slope grading should be established which would slow down any runoff and subsequent scour.

Significant areas of land are still farmed. To help retard the erosion rate conservation land treatment practices should be utilized. Some of these measures are contour farming, cover cropping, terracing, critical area planting, pasture and hayland management and stabilization.

If the above practices are not possible either in the urban or rural areas, alternative measures should be employed to help reduce the erosion. Some of these measures are debris and desilting basins, mulching of steep slope areas, or the establishment of planted buffer zones between open areas.

Reservoirs - These are designed to temporarily hold floodwaters and release them slowly to reduce flood peaks. In New England these generally consist of rolled earth and rockfilled structures for impounding uncontrolled floodwaters. They are located at strategic points within a watershed to provide flood protection to downstream communities. An important factor relating to reservoirs that should not be overlooked is their ability to satisfy other needs. Such multiple objectives result in greater utilization of the available natural resources within a watershed.

Walls and Dikes - This approach usually involves a system or a combination of concrete floodwalls, earth rockfilled dikes, and appurtenant facilities for confining floodflows to the channel or floodway. These are generally referenced as local protection projects because they provide protection to localized, high risk flood-prone areas located behind the dike system.

Reservoir Management Programs - Under certain conditions and barring any legal constraints, restrictions or conflicts, some of the major existing water impoundments within the watershed could be regulated to provide flood control storage. A plan of operation sets the drawdown limits, time and rates so that downstream flood problems are not created and upstream water rights are considered. The object of reservoir regulation is to temporarily retard peak flow long enough to desynchronize tributary flows from the flood peaks on the major rivers, then release those flows at controlled rates as the flood danger passes.

Hurricane Barriers - This measure is utilized where low-lying areas are exposed to either hurricanes or storm induced tidal surges. They consist of a system of dikes and walls along low-lying lands that are tied into a rockfilled jetty that also usually contains navigational gates and a pumphouse. When the barrier is placed into operation, the navigational gates (and street gates if any) are closed and braced and the pumps activated. These pumps are used to prevent an increase in the water surface behind the protection caused by any tributary drainage that now cannot flow out normally to the sea.

Stream Improvements - Where substantial flood damages can be attributed to the deterioration or neglect of the waterways, a rehabilitation program for improving channel conditions so as to increase their hydraulic efficiency and subsequent flood carrying capacity could generally be accomplished by the following measures:

a. To alleviate frequent flooding and subsequent flood losses various methods of channel restoration work could include:

- Possible elimination of abrupt turns and oxbows;
- Widening and deepening of certain stretches of river;
- Improvement of waterway areas at bridges and culverts;
- Removal of shoals, sandbars, and islands impeding minor floodflows; and
- Removal of overhanging trees, uprooted trees, and accumulated debris at critical points.

b. Channel improvements of restricted pondage areas by modification or removal of dams could also offer some flood relief to critically high risk flood-prone areas providing proper measures were taken to prevent excessive scour siltation.

c. The diversion of floodflows as a means of bypassing heavily congested flood-prone areas could provide an adequate and high degree of flood protection while minimizing the social and environmental impact.

CORRECTIVE NONSTRUCTURAL METHODS

Temporary and Permanent Closures for Openings in Existing Structures - Structures whose exterior is generally impermeable to water can be made to keep floodwater out by installing watertight closures to openings such as doorways and windows. While some seepage will probably always occur, it can be reduced by applying a sealant to the walls and floors and by providing a floor drain where practical. Closures may be temporary or permanent. Temporary closures are installed only during a flood threat and, therefore, need warning time for installation.

As most residential structures in this area are of wood frame construction only the basement would be considered applicable for flood-proofing. However, as many industrial and commercial establishments are constructed of concrete block with relatively few openings at zero to three feet above the first floor slab, serious consideration should be given to protecting them, even if at their owners expense. There are, however, several disadvantages to this means of protection. As mentioned above it is applicable only to structures with brick or masonry type walls, and only to a level where they can withstand the hydrostatic and uplift pressure of the floodwaters. Another disadvantage is the reduced likelihood of effective closure at nights and during vacations when temporary closures are employed; and lastly the entire measure may create a false sense of security and induce people to stay in the structure longer than they should.

Raising Existing Structures - Existing structures in flood hazard areas can often be raised in-place to a higher elevation to reduce the susceptibility of the structure to flood damage. Specific actions required to raise a structure include:

a. Disconnect all plumbing, wiring and utilities which cannot be raised with the structure.

b. Place steel beams and hydraulic jacks beneath the structure and raise to the desired elevation.

c. Extend existing foundation walls and piers or construct new foundation.

d. Lower the structure onto the extended or new foundation.

e. Adjust walls, steps, ramps, plumbing and utilities and regrade site as desired.

f. Reconnect all plumbing, wiring and utilities.

g. Insulate exposed floors to reduce heat loss and protect plumbing, wiring, utilities and insulation from possible water damage. These actions are intended to place the structure at a higher elevation at its existing site and to protect plumbing and utilities previously below the first floor from water damage. Because the hazard is not eliminated, but only the damage potential reduced, it is important that the potential for flooding below the first floor be recognized in the raising. Lateral stability of the structure should be insured by designing the foundation walls. Such design would include the use of thick concrete mats for the floor slab and a structurally designed concrete wall. Both necessitate the use of reinforcing steel.

Some of the advantages to raising a structure are as follows: Damage to structure and contents is reduced for floods below the raised first floor elevation. It is particularly applicable to single and two story structures already on a raised foundation. There are no elevation limitations to raising a structure as long as the floodwaters are allowed to pass through the basement. Finally, the flood insurance premiums for the secondary layer of coverage are drastically reduced.

Some of the disadvantages are as follows: Residential damages exist when floods exceed the raised first floor elevation. Minor damage may occur below first floor depending upon use. Measure is not generally feasible for structures with slab on grade foundations or for complete floodproofing measures where cellar flooding is not tolerated. Extensive landscaping and terracing may be necessary if the height raised is extensive. Finally, that costs are approximately 50 percent of the market value of a home, making it extremely difficult for the average homeowner to afford.

<u>Small Walls or Dikes</u> - This measure consists of a minimal height wall or dike, generally less than 6 feet and are so designed to protect one or several structures and they are built to be compatible with local landscape and aesthetics. Walls may be of any suitable material and so

designed as to resist the lateral and uplift pressures associated with flooding. Dikes are usually constructed with an impervious core to prevent seepage and with a slope protectin if erosion is a problem or both of the above where access openings are necessary, provisions must be made to close their openings during floods. Interior drainage facilities such as a small sump pump may be necessary to control the land and roof runoff.

Rearranging or Protecting Damageable Property Within an Existing Structure - Within an existing structure or group of structures damageable property can often be placed in a less damageable location or protected in-place. It is something every property owner can do to one degree or another depending upon the type and location of the susceptible property and upon the severity of the flood hazard. Some of the possibilities are as follows:

a. Protecting furnaces, water heaters, air conditioners, washers, dryers, shop equipment and other similar property by raising them off the floor. This may be appropriate for shallow flooding conditions.

b. Relocating damageable property to higher floors. Moving property from the basement to the first floor or second floor would be an example. This action usually requires altering ducts, plumbing and electrical wiring and making space available at the new location.

c. Relocating commercial and industrial finished products, merchandise and equipment to a higher floor, or adjacent and higher building, or to a less flood-prone site.

d. Anchoring all property which might be damaged by movement from floodwater.

Removal of Structures from the Flood Hazard Areas - The previous description discussed relocating and protecting damageable property within an existing structure. However, at a certain level, this is no longer feasible. This section discusses two options for removing property to a location outside the flood hazard area. One option is to remove both structure and contents to a flood free site. This involves:

a. Locating and purchasing land at a new site.

b. Preparing the new site, services, driveway, sidewalk and new foundation

c. Raising structure off its existing foundation, transporting it to the new site and placing it on this new foundation.

d. Moving contents from existing to new location.

e. Removing, disposing and backfilling the foundation at the existing site.

f. Providing temporary lodging during relocation.

A second option is to remove only the contents to a structure located at a flood free site and demolish the existing site. This measure includes:

a. Locating an existing structure, or building a new structure at a flood free site.

b. Moving contents from an existing to a new location.

c. Either demolishing, and where possible salvaging the existing structure, or reusing it for a less damage susceptible use.

WOONASQUATUCKET RIVER BASIN

The Woonasquatucket River Basin has a recorded history of flooding dating back to February 1886. Substantial flood related damages warrant investigations of the potential solutions as discussed below.

Land Treatment Measures - Based on current information the watershed does not presently have any significant erosion and sedimentation problems. The only location where streambank erosion posed a problem was in Providence Zone 2. However, this condition has been remedied by local interests in conjunction with an Urban Redevelopment Program.

For areas where possible erosion and sedimentation problems could eventually surface, assistance to alleviate those problems would be available through Soil Conservation Service programs, US Department of Agriculture. Under existing authorities Corps participation in streambank erosion measures is limited to protection of essential public facilities. Such action is not foreseen at this time.

Reservoirs - Within this study area, several reservoir sites were investigated for the purpose of reducing downstream flooding as well as satisfying other needs. Small volume reservoirs offer only a limited degree of protection to existing damage areas and they are inadequate in controlling significant drainage areas. The locations of most potential sites were considered too far removed from the heavy damage centers. Many engineering, social and environmental constraints exist and it has been determined that by and large, costs would far exceed accrued benefits. Subsequently, most of the reservoir sites considered were eliminated from further evaluation. Results of preliminary analysis indicated however, that two reservoir sites warranted more advanced investigation as multipurpose projects.

The first site was Stillwater Reservoir in Zone 5 (see Plate 2-1). The considered plan entailed modification of the existing impoundment to provide a minimum of 6 inches of flood control storage from an intercepted

drainage area of 24.5 square miles. In conjunction with flood control, the project would maintain its current recreational pool surface of 300 acres.

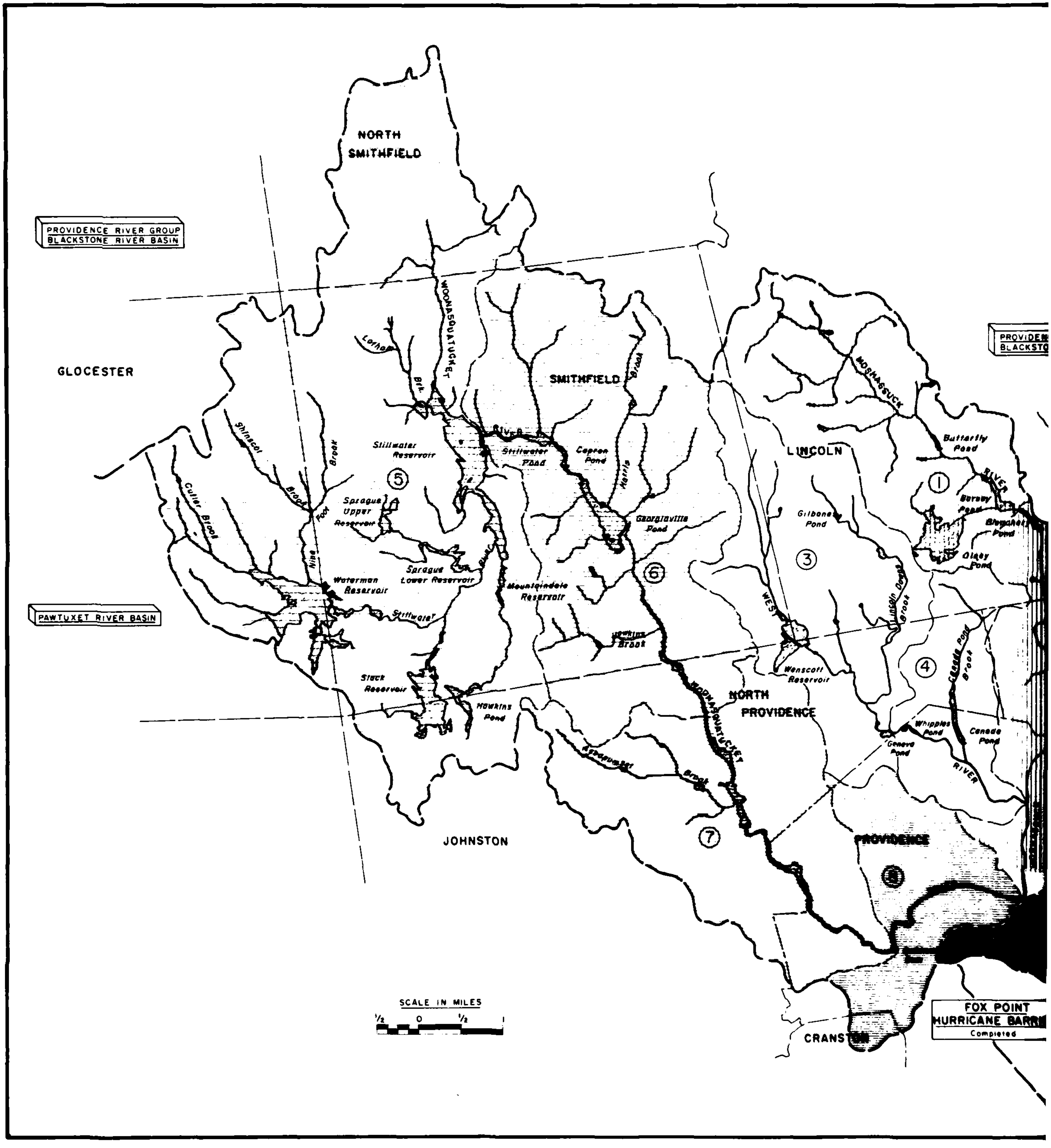
In addition to its prohibitive construction costs, a minimum of 80-year-round residential homes, businesses and commercial establishments would have to be relocated as well as numerous miles of State and local roads. With the results of more refined evaluation, it was determined that though the project would offer substantial flood reduction to the flood areas located immediately downstream, it would be ineffective for the heavily susceptible flood-prone areas occurring within the lower reaches of the Woonasquatucket River, particularly the Olneyville section of Providence.

This reasoning is due to the time lag associated with the minor peak flows emanating upstream of Stillwater Reservoir when compared to the more significant peaks downstream in the heavy damage area. By eliminating this upstream component, the net reduction is minor, necessitating some other form of protection downstream to help control the high flows. Therefore, any upstream measures would not be beneficial in the heavy damage areas making futher consideration unwarranted.

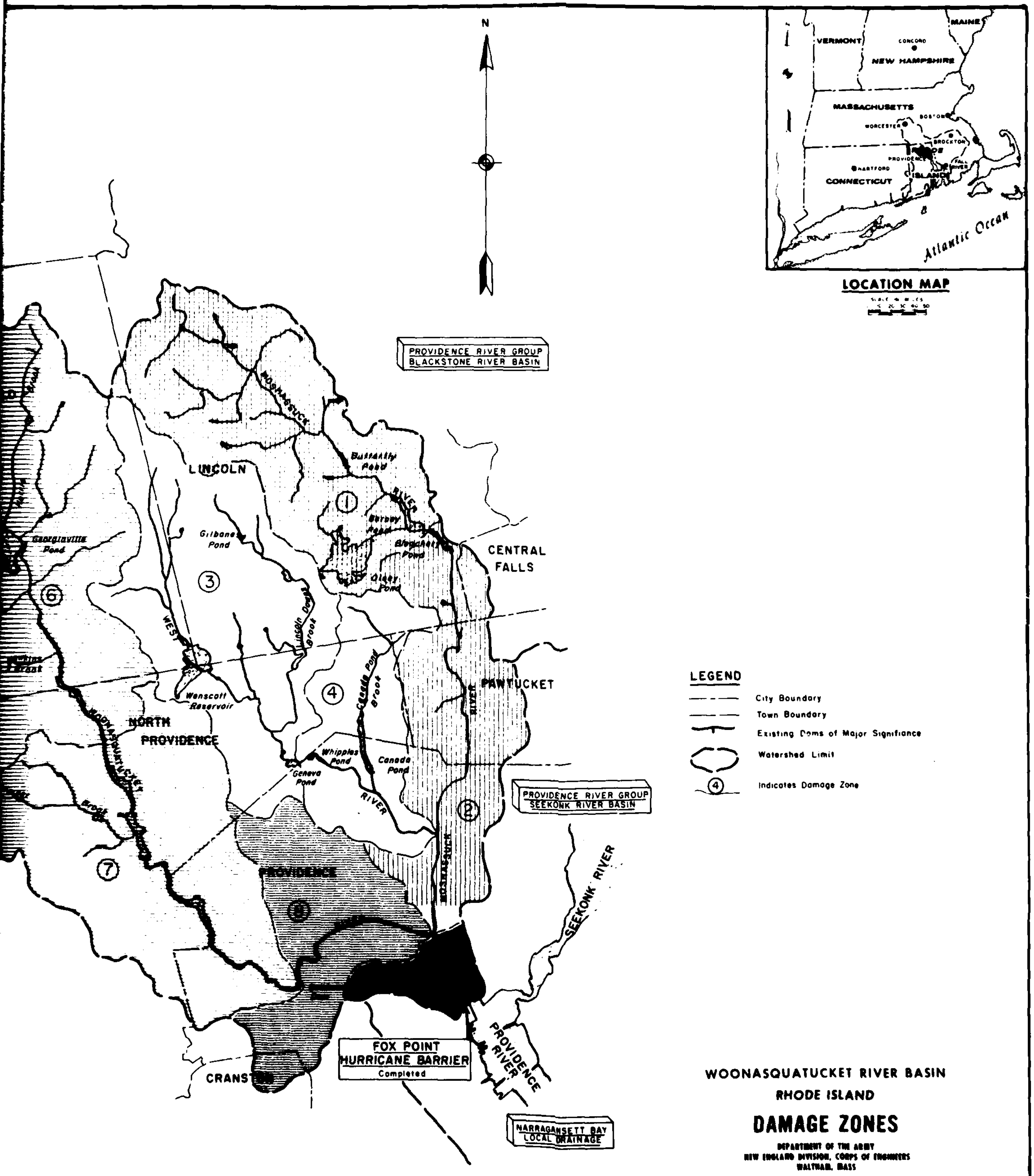
Furthermore, as improvement of the Woonasquatucket River channel in the lower reaches to contain peak floodflows appeared to have more meritorious value, the Stillwater Reservoir proposal was omitted from further evaluation.

Located in Zone 1, the second reservoir site, worthy of preliminary evaluation, involved a new multipurpose impoundment along the Moshassuck River. It would be located about 1000 feet upstream of the upper extremities of Barney Pond in Lincoln, Rhode Island. This multiple purpose solution would provide flood control, water supply and noncontact recreational activities blended in with the existing Lincoln woods reservation complex.

As a primary function of the project proposal water supply could have provided a maximum net yield of 4 mgd of water for the community of Lincoln. Preliminary findings indicated that this small amount of water supply could be provided from surface and groundwater sources from the adjacent Blackstone River Basin and from developable groundwater sources within the Woonasquatucket River Basin at less cost than surface water from this reservoir. In addition, the separable costs allocated to the flood control features would far outweigh the minimal flood control benefits derived along the downstream reaches of the Moshassuck River. Because 33 dwellings would require displacement and because of its deficiency as a water supply source, further consideration of this project proposal would be economically prohibitive, and socially and environmentally unacceptable.



NORTH SMITHFIELD
PROVIDENCE RIVER GROUP
BLACKSTONE RIVER BASIN
GLOCESTER
SMITHFIELD
LINCOLN
PAWTUXET RIVER BASIN
NORTH PROVIDENCE
JOHNSTON
PROVIDENCE
CRANSTON
WOONASQUATUCKET
MOSHASSUCK
Stillwater Reservoir
Stillwater Pond
Capron Pond
Georgiaville Pond
Sprague Upper Reservoir
Sprague Lower Reservoir
Waterman Reservoir
Mountaindale Reservoir
Slack Reservoir
Hawkins Pond
Hawkins Brook
Wenscott Reservoir
Gilbane Pond
Butterfly Pond
Barney Pond
Olney Pond
Whipples Pond
Geneva Pond
Canada Pond
Canada Pond Brook
Lincoln Downs Brook
Harris Brook
Shinscot Brook
Cutler Brook
Nine Foot Brook
Assapumpset Brook
Latham Brk.
RIVER
WEST
1
3
4
5
6
7
SCALE IN MILES
1/2
0
1/2
1
FOX POINT
HURRICANE BARR
Completed



N
LOCATION MAP
VERMONT
MAINE
NEW HAMPSHIRE
CONCORD
MASSACHUSETTS
BOSTON
WORCESTER
BROCKTON
PROVIDENCE
HARTFORD
CONNECTICUT
Atlantic Ocean
PROVIDENCE RIVER GROUP BLACKSTONE RIVER BASIN
PROVIDENCE RIVER GROUP SEEKONK RIVER BASIN
NARRAGANSETT BAY LOCAL DRAINAGE
FOX POINT HURRICANE BARRIER Completed
LINCOLN
CENTRAL FALLS
PAWTUCKET
NORTH PROVIDENCE
PROVIDENCE
CRANSTON
MOSHASSUCK RIVER
WOONASQUATUCKET RIVER
SEEKONK RIVER
PROVIDENCE RIVER
WEST RIVER
Butterfly Pond
Barney Pond
Olney Pond
Gilbane Pond
Georgiaville Pond
Wenscott Reservoir
Whipples Pond
Canada Pond
Geneva Pond
Canada Pond Brook
Lincoln Dows Brook
LEGEND
City Boundary
Town Boundary
Existing Dams of Major Significance
Watershed Limit
4 Indicates Damage Zone
WOONASQUATUCKET RIVER BASIN
RHODE ISLAND
DAMAGE ZONES
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS

PLATE 2-1

Walls and Dikes - Concrete walls and dikes, usually referred to as local protection projects, were considered an effective means for providing flood protection to high risk flood-prone areas, such as those in Zones 4, 8 and 9. Numerous buildings susceptible to high flood losses are located in these zones. Zone 9 is protected from tidal flooding by the Fox Point Hurricane Barrier, and as riverine flooding under a maximum probable event would cause only nuisance flooding, no further evaluation of this zone was warranted.

Damage Zones 1 through 7 have either isolated buildings or clusters of buildings which are subject to only minimal flood losses for which dikes or floodwalls would be economically prohibitive. Consequently, walls and dikes were eliminated from further consideration within the Woonasquatucket River Basin, except in Zones 4 and 8.

Reservoir Management Program - The basic element in a reservoir management program is provision of floodwater storage by lowering the stages in existing reservoirs, thereby reducing peak flood discharges and potential damages. Within the study area there are numerous impoundments which could provide storage to warrant inclusion in a reservoir management system. Although not originally designed for flood control, these impoundments have actually acted to reduce flood crests appreciably in the past. Further evaluation of existing impoundments in Zones 7 and 8 was deemed economically infeasible, socially unacceptable and technically impractical as these would provide insufficient flood control storage and their modification costs, involving either their rehabilitation or raising would far outweigh the benefits to be derived. In Zone 9 there are no existing impoundments thereby obviating further investigation.

Hurricane Barrier - The Fox Point Hurricane Barrier as currently designed and operated can handle storms equivalent to a Standard Project Tide synchronized with the peak flow from a 100-year riverine flood. Riverine flooding in excess of the designed pumping capacity of 7000 cfs could cause flooding in downtown Providence - the severity of flooding being solely dependent on the excess flows associated with the flood frequency event.

The Standard Project Flood (SPF) criteria for riverine flooding in the watershed would be equivalent to a flow of 24,000 cfs at the barrier. Under current conditions a pumping capacity of 7000 cfs would cause nuisance damages in Providence. However, with a maximum 24,000 cfs flow or an excess of 17,000 cfs water depths would average about 2 feet in downtown Providence resulting in substantial flood losses.

One method of minimizing or overcoming this flooding problem, is increasing the pumping capacity of the Fox Point Barrier. This would involve modification of the structure. The extent of modification would be dependent on the magnitude of flows to be pumped from the interior drainage area.

By considering the rarity of such events and costs associated with any degree of protection in excess of the current 7000 cfs pumping capacity of Fox Point, it was determined that any modification cost to the barrier would far outweigh the benefits to be derived. Therefore, no further evaluation is warranted, particularly when other nonstructural measures would be far more economical and socially acceptable.

Stream Improvements - The channel conditions of some of the major streams within the basin have been neglected to such a degree that their deterioration has alarmingly affected their hydraulic efficiency. The flooding condition has also been aggravated by siltation, riverbank and lowland encroachment, inadequate bridge and culvert openings, structural obstruction such as buildings spanning the river with inadequate waterway area, or general neglect in the removal of excessive vegetative growth and accumulated debris.

Means of remedying these conditions would be evaluated within the realm of three major elements, namely: removal of dams, diversion of floodflows and channel modification.

a. Removal of Dams - Within the basin there are numerous dams serving the needs of the area. Some impound substantial water bodies for industrial purposes while others have recreational and water supply values. Many of the smaller dams, generally those run-of-the river type originally intended for power generation or for processing water, have not only been neglected but have become obsolete. Their siltation has caused restricted pondage and has impeded normal riverflow.

Removal of dams that no longer serve a meaningful purpose would appear to be beneficial by reducing flood stages and damages in their immediate vicinities. However, there are detrimental effects of shifting the hydraulic control to other critical downstream locations. The resultant streambank erosion problems associated with subsequent increased water velocities would outweigh the beneficial values to be derived.

In conclusion, the removal of dams for all zones was considered to be an inadequate solution for solving flood problems within the watershed and further evaluation was deemed unwarranted.

b. Diversion of Floodflows - Two basic methods could be used as an effective means of providing flood relief to high risk flood-prone areas. One would involve an intrabasin diversion of floodflows and the other an interbasin transfer. In the application of either methodology, care must be exercised in that the problems of one area are not transferred to another unless mitigating measures could be feasibly applied.

Within the study area, numerous intrabasin and interbasin schemes of bypassing floodflows around or away from heavy damage zones were evaluated. Based on a preliminary screening damage analysis of all zones,

only Zones 1 and 8 appeared to have some initial merits; all other zones were found to be technically, economically or socially unacceptable.

With further evaluation of Zones 1 and 8 any scheme involving an interbasin or intrabasin transfer of floodflows proved to be nonviable, and further evaluation was deemed unwarranted for the following reasons:

In Zone 1 an interbasin transfer of floodflows from Bleachery Pond, located immediately downstream of Barney Pond, to the Blackstone River via Scott Pond was considered as a means of alleviating some of the flood problems scattered along Zone 2 of the Moshassuck River. This scheme was rejected on the basis that the Blackstone River has its own flood problems and any further increases in floodflows, regardless of their magnitude, causing negligible increases in flood stages along the lower Blackstone River is unadvisable. Its acceptability by abutters along the flood-prone areas of the Blackstone River is questionable. Furthermore, as the proposed route of diversion would require a substantial lowering of Scott Pond thereby limiting, even eliminating, existing recreational activities, such a proposal would have a social and environmental impact rendering its consideration totally unacceptable. As the benefits to be derived from such a scheme would be far less than the investment, further evaluation was unwarranted.

To alleviate the major potential flood losses of Zone 8, two diversion schemes were investigated. The first scheme would divert excess Woonasquatucket River floodflows via a deep 2.5 mile underground tunnel from Bulkhead Dam located at the junction of Zone 7 with Zone 8 to an outfall on the shore of the Providence River below Fox Point Barrier. Inasmuch as this scheme would be technically feasible, the related costs would far outweigh the derived benefits. Furthermore, considered tunnel alignments would pass under a high density mixed use area with numerous commercial and industrial complexes. Based on similar past studies of such a proposal by this office in a far less densely populated area, the mere knowledge of a large-sized underground tunnel and easements upon deeds would result in a significant social disruption as well as potential lowering of land values.

Consequently, based on its economic infeasibility and social unacceptance, this diversion scheme was eliminated from further consideration.

The second diversion scheme would also bypass Woonasquatucket River floodflows from the same initial point at Bulkhead Dam via a conduit into the adjacent Pocasset River within the Pawtuxet River watershed. As this adjoining watershed has its own flood problems of a very severe nature, the proposal would be an inadequate solution. It was primarily evaluated on a cursory basis due to its coverage in prior reports.

c. Channel Modification - The final stream improvement element would consist of channel modification involving a rehabilitation program for improving the waterways. The methods considered include channel widening, deepening, and elimination of abrupt turns and oxbows in numerous mainstem and tributary reaches. it also included channel enlargement at constriction points in order to eliminate blockage of normal flows.

As the flood problems of the watershed in Zones 1 and 5 are relatively minimal and mostly unrelated to channel modification, further evaluation would be unwarranted. Channel modification would also be economically and hydraulically impractical for flood stage reductions in Zones 2, 3, 6 and 7 due to either the flat hydraulic gradient or the excessive depths of flooding to be encountered. Many areas are heavily urbanized with numerous structures abutting or in close proximity to the river rendering channel modification economically infeasible.

In Zones 4 and 8, investigations were warranted in these most heavily urbanized sections of the basin.

Floodproofing or Relocation - As flood problems within Zones 1 and 5 were determined to be minimal, no further evaluation was required in those zones. For the remaining zones, floodproofing or relocation may warrant further evaluation on an individual basis.

As the roles of the No Action program and all regulatory measures are oriented to fulfilling projected needs and to establishing appropriate measures for preventing or minimizing future flood problems, their importance for further evaluation, particularly as a supplement to corrective measures merit consideration. Consequently, both programs were retained for future analysis in all study zones.

Development of Detailed Plans

This phase of the plan formulation efforts combined the single action measures that were considered feasible for the intermediate level. Detailed analyses were conducted on each alternative in this stage. Alternatives involved various combinations and design levels. One of the alternatives consisted of the No Action plan. All alternatives assumed that flood insurance would be available for the various communities within the watershed. This would help eliminate future flood losses to new development as strict floodplain zoning would be enforced. The remainder of the planning process dealt with the derivation of detailed costs, benefits, and evaluation of various flood control systems.

The major components of the three alternative plans for the Woonasquatucket River are described in the following paragraphs. Preliminary cost estimates are included in Appendix 4.

Alternative A - This alternative would provide protection to the Standard Project Flood (SPF) level along the Woonasquatucket River in the Olneyville section of Providence. It would consist of:

- Removal of 3 dams (Paragon, Rising Sun, and Bulkhead Dams),
- Replacement of 1 Dam (Bulkhead Dam),
- Removal of 11 bridges,
- Replacement of 8 of the bridges removed,
- 6900 feet of concrete "U" shaped channel from Bulkhead Dam to Acorn Street.
- Removal of 4 buildings,
- Replacement of 2 of the buildings removed,
- 700 feet of concrete transition channel,
- Removal of 900 feet of masonry walls,
- Earth support system and underpinning,
- Box conduit,
- Diversion weir,
- Concrete rectangular channel section,
- Pumping station,
- Trapezoidal channel with stone slope protection from Acorn Street to Crawford Square.

The cost of Alternative A is $53.5 million (1977 Price Level).

Alternative B - This alternative would provide protection to the 300-year event level along the Woonasquatucket River in Olneyville. It would consist of:

- Removal of 3 dams (Paragon, Rising Sun, and Bulkhead Dam),
- Replacement of Bulkhead Dam
- Removal of 10 bridges,
- Replacement of 6 bridges
- Removal of 2 buildings,
- Replacement of 2 buildings,
- Removal of 900 feet of masonry walls,
- Earth support system and underpinning,
- Concrete "U" shaped channel (8270 feet),
- Concrete rectangular channel section,
- Box conduit,
- Diversion weir,
- Trapezoidal channel with stone slope protection (6360 feet).

The cost of Alternative B is $32.1 million (1977 Price Level).

Alternative C - This alternative would provide protection to the 100-year event level along the Woonasquatucket River in Olneyville. It would consist of:

- Removal of 3 dams (Paragon, Rising Sun, and Bulkhead Dam),
- Replacement of 1 dam (Bulkhead Dam),
- Removal of 10 bridges,
- Replacement of 6 bridges,
- Removal of 2 buildings,

- Replacement of 2 buildings,
- Removal of 900 feet of masonry walls,
- Earth support system and underpinning,
- Concrete "U" shaped channel,
- Concrete rectangular channel section,
- Box conduit,
- Diversion weir,
- Trapezoidal channel with stone slope protection.

The protection scheme of Alternative C is identical to Alternative B but with reduced channel sizes. The cost of Alternative C is $28.7 million (1977 Price Level).

Along the West and Moshassuck Rivers minor channel modifications—clearing and deepening—were considered, however, it was determined that the reduction in flooding would be relatively minor and substantially less than the 100-year flood level. A major modification scheme was investigated in detail. This project involved clearing and deepening the channel, reconstruction of several bridges, a bascule gate, a weir and two conduits.

The estimated cost is $24,309,000 and average annual charges are $2,067,400. Benefits are approximately $860,000. The resulting benefit-to-cost ratio is 0.42 to 1.00 (see Appendix 4).

Another flood control project considered on the West River was a ringwall that would surround the industrial/commercial complex at 387 Charles Street. This would not reduce flood elevations but would prevent water from entering the complex and provide protection to either a 100-year flood or SPF level depending upon the height of the walls. However, a ringwall would not only keep water out, it would also keep water in the industrial complex. The cost of the ringwall combined with the cost of providing interior drainage and pumps to expel the water from inside the area eliminates this plan from evaluation.

Summary

As a result of more in-depth analysis on the solutions considered above, it is apparent that structural measures in the Woonasquatucket River basin do not warrant Federal expenditure. Several nonstructural solutions were also investigated.

They too were not economically feasible for Federal expenditure of funds. A combination of the two in a systems analysis lacked the required benefit-to-cost test that must be applied prior to recommendation of a plan. In order to preclude a situation where the conditions become more favorable for flooding it is recommended that all the communities in the watershed, particularly those in the upper portions where wetlands remain in relatively undisturbed conditions enact strict flood plain zoning so

that development be kept out of the 100-year flood plain. If urbanization continues unchecked in portions of the basin, future increased flooding can be expected to occur or be increased in existing urbanized areas.

PAWCATUCK RIVER BASIN

Land Treatment Measures - As in the Woonasquatucket watershed, current information indicates that the Pawcatuck watershed does not presently have any significant erosion and sedimentation problems.

Reservoirs - Within this study area three reservoir sites were considered for the purpose of reducing downstream flooding. The first potential site was Great Swamp and Worden Pond in South Kingston. The second site was the Chapman Pond area in Westerly and the third was Indian Cedar Swamp in Charlestown. The primary reasons associated with the elimination of the reservoir sites were that they did not control adequately sized drainage areas or their locations were so remote from the damage areas that costs would have been prohibitive. Also, as these swamps in their natural state act, to a degree, to control floodflows preservation of these areas would be more economical.

Walls and Dikes - A system of walls and dikes, also known as a local protection project was considered for the high risk flood-prone area of Westerly, Rhode Island near the mouth of the Pawcatuck River. However, based on the costs of the Pawcatuck Local Protection Project in Stonington, Connecticut, a project of this type and magnitude would not be economically justified. The Pawcatuck LPP provides protection to an industrial area having higher losses than the residential/commercial area in Westerly.

Reservoir Management Program - There are few large impoundments in the Pawcatuck study area and none with a reliable gated outlet to allow for desynchronization of peak flows. Further evaluation of the reservoir management program was eliminated after it was deemed economically infeasible, socially unacceptable, and technically impractical as the existing reservoirs would not provide sufficient storage and their modification costs for rehabilitation or raising would far exceed the benefits to be derived.

Stream Improvements - Within the study area there are numerous small dams originally intended for power generation or process water which have been neglected and have become obsolete. Their siltation has caused restricted pondage and some impedance to normal riverflows. However, the dams on the Pawcatuck River and its tributaries do not cause any major problems and as virtually all are privately owned and therefore not eligible for Federal expenditures they were eliminated from further consideration.

Floodproofing or Relocation - Some floodproofing measures might prove to be economically justified for single structure establishments or residences. Relocation may warrant further evaluation where one or two isolated structures suffer frequent heavy damages, especially to contents.

Summary

It is evident that no structural or nonstructural solutions warrant Federal expenditures. However, in order to preclude a situation where conditions become more favorable for flooding, it is recommended that all communities in the watershed, particularly those in which wetlands remain in relatively undisturbed conditions, enact strict flood plain zoning. If uncontrolled urbanization is allowed in the flood plain, future increased flooding can be expected to occur.

NARRAGANSETT BAY LOCAL DRAINAGE

Land Treatment Measures - As in the Woonasquatucket and Pawcatuck watersheds, there are presently no significant erosion and sedimentation problems.

Reservoirs - There were no reservoir sites considered in the local drainage area.

Walls and Dikes - Concrete walls and dikes, generally referred to as local protection projects are an effective means of providing flood protection to high risk flood-prone areas. Initially 24 sites in the Narragansett Bay Local Drainage Area were identified as susceptible to significant hurricane damages. Six local protection project sites were then proposed for the Narragansett Bay coastal area--Greenwich Bay Hurricane Barrier, Rumstick Neck and Kickamuit River Barrier, Bullock Cove Barrier, the Pettaquamscutt River Narrows Barrier, Wickford Harbor Barrier and the Easton Beach Barrier. A seventh project, a system of walls and dikes at the mouth of the Seekonk River on the east bank, was later investigated. Although the consultants reports (see Appendix 4) indicate that some of the projects may be economically justified (BCR greater than 1.0), all of these projects were excluded from further consideration due to lack of local support.

Reservoir Management Program - As in the Woonasquatucket and Pawcatuck watersheds, there are no suitable reservoirs in the local drainage study area. The reservoir management program was therefore eliminated from further consideration.

Hurricane Barriers - There has been a long history of severe hurricane tidal damages in the Narragansett Bay area. An in-depth report entitled "Hurricane Survey, Narragansett Bay Area - Rhode Island and Massachusetts" was prepared by the Corps of Engineers in January 1965. The recommended plan consisted of three barriers in the entrances to the Bay, the East and West passages and the Sakonnet River, with appurtenant

works. There was strong support for the lower bay barriers by Massachusetts residents, however, many cities and towns in Rhode Island expressed an unwillingness or inability to participate financially in the project. Opposing interests cited pollution control as being more urgently needed and feared possible adverse effects of the barriers on water quality, fishery, navigational and water resource aspects of the bay although detailed technical studies indicated that any adverse effects would be minimal. Due to a lack of local support for the hurricane barriers, further consideration was terminated.

Stream Improvements - Insufficient channel maintenance can result in deterioration of hydraulic efficiency. This deterioration is due to siltation, riverbank or wetlands encroachment, inadequate bridge and culvert openings or general neglect in the removal of excessive vegetative growth and accumulated debris. Although relatively insignificant for a major flood these conditions can cause increased flood stages and damages at a frequent-type storm event.

Floodproofing or Relocation - As in the Woonasquatucket and Pawcatuck watersheds some floodproofing or relocation measures may be justified where one or two isolated structures suffer frequent heavy damages, especially to contents.

Summary

Although no structural or nonstructural solutions warrant Federal expenditures in the Narragansett Bay Local Drainage Area, it is recommended that the local authorities enact strict flood plain zoning to prevent uncontrolled urbanization and future increased flooding.

APPENDIX 3
PUBLIC INVOLVEMENT

APPENDIX 3: PUBLIC INVOLVEMENT

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DESCRIPTION OF PUBLIC INVOLVEMENT PROGRAM

In keeping with the policy of the Chief of Engineers to conduct his Civil Works program in an atmosphere of public understanding, trust, and mutual cooperation, all interested individuals and agencies were informed and afforded an opportunity to be fully heard and their views considered in arriving at conclusions, decisions, and recommendations in the formulation of civil works proposals, plans, and projects and on the proposed uses of navigable waters. Formally organized and announced public meetings provide one important means of accomplishing this objective. Other desirable public participation and information measures such as workshops and close coordination between towns and individuals also contributed to this objective.

Formality is intended only in respect to organization and announcement. The atmosphere of the meetings were informal to the extent practicable, in keeping with the concept of public involvement and the need to encourage and develop more meaningful, two-way communication.

The primary purpose of the public meetings was to help to insure that solutions to flooding problems satisfy the needs and preferences of the people to the maximum degree possible within the bound of local, State, and Federal interests, responsibilities, and authorities. More specifically, the purposes of the public meetings were to inform the public about studies and proposals related to flooding and to give all interested persons an opportunity to fully and publicly express their views concerning such studies and proposals; to obtain and exchange information which will assist all those involved in arriving at sound conclusions and recommendations; and to contribute to interagency coordination.

To afford local citizens, municipal and State officials, and other Federal agencies an opportunity to present their views and desires concerning the need and extent of improvements on flood reduction measures and other interrelated water-oriented resources, four public hearings, 5, 12, 15 and 22 May 1969, were held at the initiation of the study. Though these four public hearings were intended to cover the entire Pawcatuck River and Narraganseet Bay Drainage Basin (PNB) study area, as mandated by seven Congressional Resolutions, two of these hearings were held in Providence and Kingston, Rhode Island--both within the area of concern in this study.

All interested parties were invited to be present or represented at these hearings, including representatives of Federal, State, county and municipal agencies, and those commercial, industrial, civic, highway, railroad, water transportation, flood control and other interests, and property owners concerned. They were afforded full opportunity of expressing their views concerning the character and extent of the improvements desired and the need and advisability of their execution. Sponsors of improvement measures were urged to present pertinent factual

material bearing upon the general plans of improvement desired and to give detailed supporting data on the economic justification of the undertaking. Opposing interests were also urged to state the reasons for their position.

Oral statements were heard and for accuracy of the record, all important facts and arguments were submitted in writing, some handed to the hearing officer and others mailed to his office.

Most of the attendees supported and concurred in this study. Excerpts from the record which reflect their general attitude follow:

The General Manager of the Rhode Island Water Resources Board brought attention to the State water supply plans which, through development of new surface reservoirs and groundwater supplies, would provide the State with an adequate supply for all purposes up to the year 2020. These plans were presented in order that proper consideration would be given in light of the flood control studies.

The Warwick City Planner, who represented the Mayor, spoke about the damage created by the flood of March 1968 and the city's concern and interest in the investigation. His realm of concern centered on the intensification of land utilization causing faster runoff of surface waters in the rivers, thereby giving greater impetus to future flooding.

A representative of the Appalachian Mountain Club (AMC), Narragansett Chapter, urged that restraint, wherever possible, be used when study considerations include alteration or modification of natural streams and that all ecological factors be weighed. The organization supported abatement of all pollution and hoped that watershed areas developed for water supplies be not restricted to public recreation.

Upon completion of the consultant's report on local protection projects in Narragansett Bay, the communities affected were notified of the outcome. None expressed interest in further study of any of the projects.

In February 1977, letters with basin outlines and river profiles were sent to interested organizations and individuals announcing the commencement of the Pawcatuck River Basin portion of the PNB study. Pertinent information and comments were requested--few replies were received. A sample copy of that letter and the 1969 public meeting notices are included here.

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
424 TRAPELO ROAD
WALTHAM, MASSACHUSETTS 02254

REPLY TO
ATTENTION OF:
NEDPL-BC

This letter is to inform you of the Corps of Engineers activity in the Pawcatuck River Basin. Our efforts are a part of a study to determine the advisability and feasibility of a flood management plan for the basin. It should be noted that the Pawcatuck River Basin Study is also part of a much larger flood management study involving the Pawcatuck River-Narragansett Bay Drainage Basins (PNB). This larger study area encompasses essentially all of Rhode Island and large portions of eastern Massachusetts. The overall PNB study is scheduled to be completed this year, the recommendations for all Pawcatuck River Basin will be a part of this study report.

Work recently completed in the Pawcatuck River Basin involved the preparation of base maps and river profiles. Attached for your information are two copies of each map and profile. We would appreciate any comments or corrections. Additionally, any 1968 high water elevations in the area, especially in the swamp areas, would be useful. Mark-up one copy and return to us in the inclosed addressed envelope.

Currently, we are making a hydrologic analysis of the basin with particular emphasis on the effectiveness of the existing wetlands and how they modify flood flow. Flooding is not now a serious problem and this may be due to the numerous wetlands and their location along the river. When our investigation is complete, various alternatives will be presented and a public meeting will be held to discuss them. Subsequently, a feasibility report will be prepared.

For further information or comments, please do not hesitate to call us -- (617) 894-2400, Extension 538 or 546.

Incl
as stated

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION. CORPS OF ENGINEERS
424 TRAPELO ROAD
WALTHAM, MASSACHUSETTS 02154

IN REPLY REFER TO

NEDED-R

16 April 1969

NOTICE OF PUBLIC HEARINGS
ON
PAWCATUCK RIVER AND NARRAGANSETT BAY DRAINAGE BASINS,
RHODE ISLAND, MASSACHUSETTS AND CONNECTICUT
FOR STUDY OF
WATER AND RELATED LAND RESOURCES

Pursuant to the following initial resolution, adopted 29 March 1968 by the Committee on Public Works of the United States Senate, the Division Engineer has been directed to make a survey of the Pawcatuck River and Narragansett Bay Drainage basins:

> "RESOLVED BY THE COMMITTEE ON PUBLIC WORKS OF THE UNITED STATES SENATE, That the Board of Engineers for Rivers and Harbors, created under Section 3 of the River and Harbor Act approved June 13, 1902, be, and is hereby requested to review the report on Land and Water Resources of the New England-New York Region, transmitted to the President of the United States by the Secretary of the Army on April 27, 1956, and subsequently published as Senate Document Numbered 14, Eighty-fifth Congress, with a view to determining, in light of the heavy damages suffered during the storm of March 1968, in southern New England, the advisability of improvements, particularly in the Pawcatuck River Basin, Rhode Island, and in the Narragansett Bay Drainage Basin, Massachusetts and Rhode Island, in the interest of flood control, navigation, water supply, water quality control, recreation, low-flow augmentation, and other allied water uses."

As a result of the major flood of March 1968 and subsequent to the 29 March resolution, four other resolutions with particular references to the Pawcatuck River and the Narragansett Bay Drainage Basins and to specific localities in the Narragansett Bay Drainage Area, were adopted

by the United States Senate and the House of Representatives. The area to be studied is shown on the attached map.

In order that the desires of local interests shall be recognized and the required report fully cover the matter, four public hearings will be held at the following locations:

1st Hearing

Taunton Municipal Lighting Auditorium
55 Weir Street
Taunton, Massachusetts
on Friday, 9 May 1969, at 8:00 p.m.

2nd Hearing

Providence Journal Auditorium
75 Fountain Street
Providence, Rhode Island
on Monday, 12 May 1969 at 8:00 p.m.

3rd Hearing

Uxbridge High School
Capron Street
Uxbridge, Massachusetts
on Thursday, 15 May 1969, at 8:00 p.m.

4th Hearing

University of Rhode Island
Main Ball Room
Kingston, Rhode Island
on Thursday, 22 May 1969, at 8:00 p.m.

The Narragansett Bay Drainage Basin comprises all watersheds draining into the bay and the Atlantic Ocean between the Massachusetts-Rhode Island state line and Point Judith, Rhode Island. The chief tributaries are the Taunton, Blackstone, and Pawtuxet Rivers, with sub-basin areas of about 540, 540, and 230 square miles, respectively, or about 70 percent of the total Narragansett Bay drainage area of 1870 square miles.

The Blackstone River, rising north and west of Worcester, Massachusetts, flows southeasterly through southern Massachusetts and

northeastern Rhode Island into the Seekonk River, which empties into the Providence River Estuary.

The Taunton River lies entirely in southeastern Massachusetts and empties into Mount Hope Bay near Fall River, Massachusetts. The central portion of Rhode Island is drained by the Pawtuxet tributary.

The Pawcatuck River Basin, also included in this study, lies west of, and adjacent to, the Narragansett Bay drainage area and covers about 250 square miles of western Rhode Island and about 60 square miles of southeastern Connecticut. The lower nine miles of the river comprises the state line between Connecticut and Rhode Island.

The study area encompasses all or portions of 106 cities and towns with a total 1960 population of 1,540,000. Several important cities and towns with highly concentrated populations line the Blackstone, Taunton, and Providence Rivers. Other cities are located on the lesser tributary rivers in the area.

The study area is susceptible not only to storms of local origin and continental storms borne by the "prevailing westerlies," but also to those coastal storms and hurricanes of tropical origin to which the New England coastal area is vulnerable. The disastrous flood of August 1955 was caused by the torrential rains which accompanied Hurricane Diane. Flood damages in the Blackstone River Basin at the time were estimated at nearly $68 million.

There were no Federal flood control projects in operation in the study area in 1955. In the Blackstone River Basin the West Hill Dam on the West River and the Worcester Diversion Project and local protection projects for Upper Woonsocket and Pawtucket on the Blackstone River had been authorized. Local protection for Lower Woonsocket was subsequently authorized in 1960. Except for the Pawtucket local protection, all of these projects have since been constructed and put into operation. It is estimated that they prevented $8 million in damages in the basin in the flood of March 1968.

Constricted channels and built-up flood plains pose a continuing threat of serious flooding in the study area in widely scattered locations. For example, damages from the March 1968 flood, a record flood in much of the study area, included $2.5 million in the Olneyville section

of Providence, Rhode Island, and nearly $1 million in Taunton, Massachusetts.

There were 18 recorded hurricane occurrences in the Narragansett Bay area in the period 1901-1963, 3 of them causing severe tidal flooding. Projects to reduce hurricane tidal flooding have been completed at Pawcatuck, Connecticut and Providence, Rhode Island.

The authorized investigation will inventory the existing water and related land resources, determine future needs, and develop a plan to meet both the immediate needs and future long-range needs. Important considerations in the investigation will include the basin flood of record, March 1968, tidal hurricanes, flood plain management and insurance programs, shore protective measures, and improvement of navigation for commercial and recreational interests. Pollution of the rivers, the need for maintaining open lowland spaces in the interest of flood storage, flow augmentation, flow regulation, recreation, and aesthetic values will also be considered.

All interested parties are invited to be present or be represented at the above hearings, including representatives of Federal, State, county, and municipal agencies, and those of commercial, industrial, civic, highway, railroad, water transportation, flood control, and other interests, and property owners concerned. They will be afforded full opportunity to express their views concerning the character and extent of the improvements desired and the need and advisability of their execution. Sponsors of improvement measures are urged to present pertinent factual material bearing upon the general plans of improvement desired and to give detailed supporting data on the economic justifications of the undertaking. Opposing interests, if any, are also urged to state the reasons for their position.

Oral statements will be heard, but for accuracy of the record all important facts and arguments should be submitted in writing, in quadruplicate. Written statements may be handed to the Hearing Officer at the hearing or mailed to the undersigned beforehand.

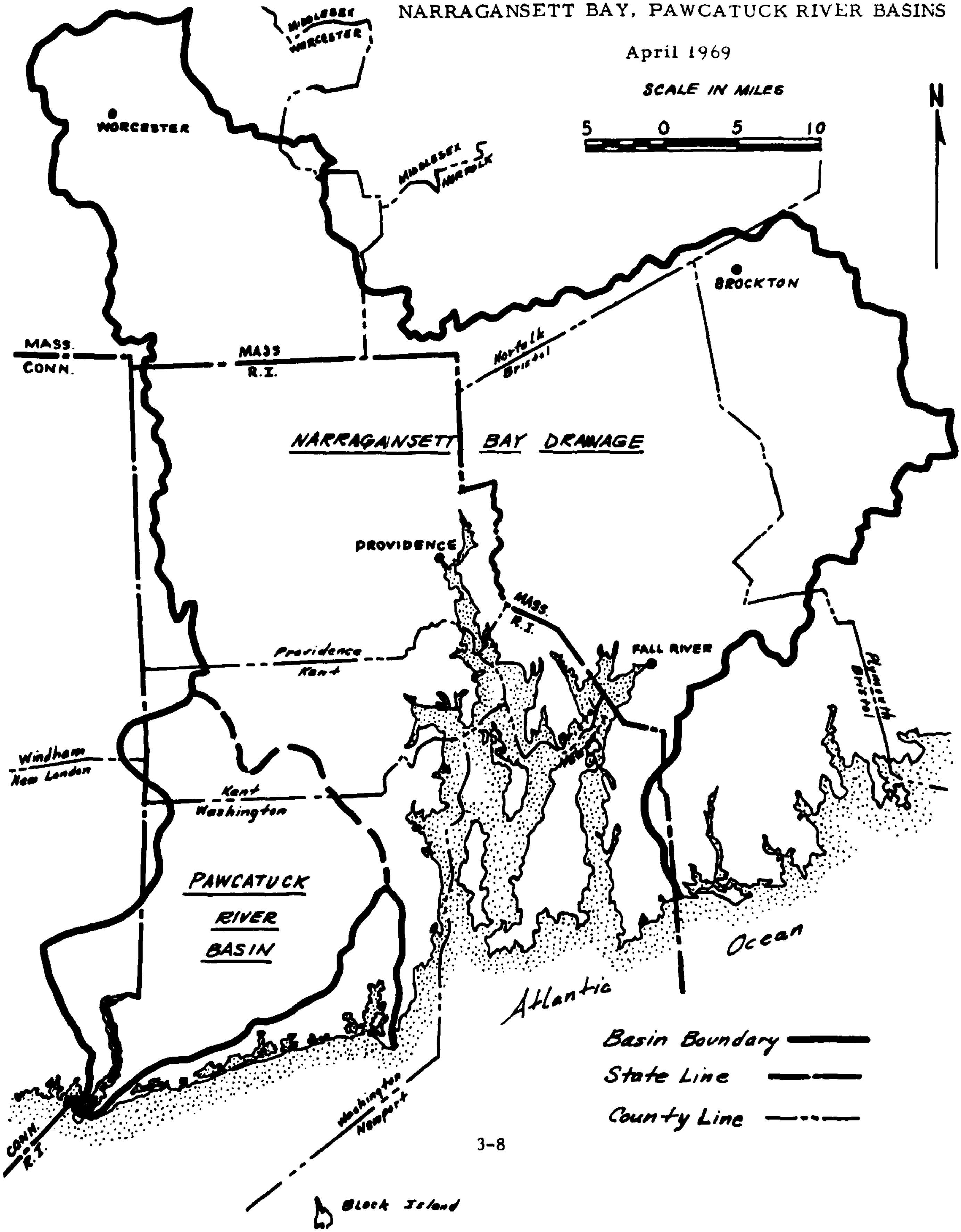
Please bring the foregoing to the attention of persons known by you to be interested in this matter.

FRANK P. BANE
Colonel, Corps of Engineers
Division Engineer

Incl.
Map

NARRAGANSETT BAY, PAWCATUCK RIVER BASINS

April 1969



APPENDIX 4
ENGINEERING INVESTIGATIONS

APPENDIX 4: ENGINEERING INVESTIGATIONS

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APPENDIX 4: ENGINEERING INVESTIGATIONS

Appendix 4 is a compilation of the various engineering studies which were completed during the course of the study. The first component is a summary of geologic conditions in each of the three areas. Also included are excerpts from the 1977 Preliminary Study of Six Coastal Flooding Projects, Narragansett Bay, Rhode Island. These excerpts are the descriptions of the eight projects investigated by the consultant. This is followed by a preliminary study of a local protection project at the Seekonk River in East Providence, Rhode Island. The hydrologic analysis of floods in the Moshassuck River basin provided the basis for the cost estimates for channel improvements on the West and Moshassuck Rivers.

GEOLOGY

PAWCATUCK RIVER BASIN AND NARRAGANSETT BAY LOCAL DRAINAGE AREA

A. BASIN TOPOGRAPHY

1. Pawcatuck River Basin

The majority of the Pawcatuck River Basin is located in the central section of Rhode Island; however, its western edge extends into eastern Connecticut. The basin, which lies within the Seaboard Lowland section of the New England Physiographic Province, has an irregular topographic surface consisting of relatively low hills in the northern and western section gradually decreasing in relief toward the south. The maximum elevation is approximately 530 feet above sea level in North Stonington, Connecticut. The basin topography is characterized by unconsolidated glacial materials with bedrock exposures on some hillsides and hilltops.

The river valley trends northeasterly from Westerly and meets the Wood River which flows from the north. These meandering rivers drain the irregular topography including some extensive swamps in the southern section of the basin.

Except in the town of Westerly, modification of landforms by cuts and fills are minimal throughout the basin, apparently due to the relatively rural character of the basin. Most of the urbanization of the basin has taken place in the southwest corner of the basin along the Pawcatuck River.

2. Narragansett Bay

Narragansett Bay with the adjacent coastal streams area and Block Island are located within the south and eastern section of the State of Rhode Island extending into a portion of southeastern Massachusetts.

Except for Block Island, the study area lies within the Seaboard Lowland Section of the New England Physiographic Province. Block Island may be considered as part of the Coastal Plain Province of the Atlantic Plain Physiographic Division. The study area has an irregular topographic surface consisting partly of low hills in the northern and western sections gradually becoming nearly level in the vicinity of the bay. Four major islands are included in the study. The islands are, in decreasing size, Aquidneck, Conanicut, Block and Prudence. A number of smaller islands also occur in the area. All islands are relatively low with little relief.

The highest ground surface elevation in the study area is approximately 430 feet above mean sea level (msl) along the west central boundary. The maximum elevation at the southern extremity of the area is

about 140 feet above msl on Block Island. The highest ground surface elevation on the largest island, Aquidneck, is about 270 feet above msl. The topography of the study area is characterized by unconsolidated glacial materials with bedrock exposures on many hillsides, hilltops, and along the shoreline. Modifications of landforms by cuts and fills are extensive in the highly urbanized areas, especially in Providence and East Providence. In addition, the military bases at Quonset and Newport have undergone considerable changes in landforms due to filling. Improvements to waterways along the south shore of Rhode Island have also resulted in significant changes to the landforms.

B. SURFICIAL GEOLOGY

1. Pawcatuck River Basin

Unconsolidated glacial deposits mantle the bedrock surface in varying degrees throughout the basin. The greatest exposure of bedrock and the thinnest surface cover is evident on the sides and tops of low hills in the western and northern section of the basin, encompassed by the towns of West Greenwich, Exeter and North Stonington. Surficial deposits are primarily derived from deposition from glacial action. Postglacial deposits are lesser in extent and occur as alluvium and swamp deposits near streams and in blocked drainage areas on hills. Extensive swamps contain varying amounts of soft organic silt and peat.

2. Narragansett Bay

Unconsolidated glacial deposits blanket the bedrock surface in varying degrees throughout the basin. The exception is Block Island, where ancient unconsolidated sediments lie between the glacial deposits and the bedrock. The greatest exposures of bedrock and thinnest surface cover occur on the sides and tops of hills along the western and northern boundaries of the study area. In addition, the islands of Aquidneck, Conanicut, and Prudence have a relatively thin cover of glacial deposits with many bedrock exposures along the shoreline. Surficial deposits are primarily derived from deposition involving glacial action. Postglacial deposits occur as shallow swamp deposits of organic silt and peat, and beach deposits of sand and gravel.

Principal deposits in the study areas are comprised of, but not limited to the following:

Glacial Till (Ground moraine) - Till consists of an unsorted mixture of rock particles ranging from clay-size to boulders. It has the most widespread occurrence, covering hills and lowlands.

Outwash Plains - Outwash plains are flat-topped, broad accumulations deposited in open areas by glacial meltwater. They consist of sands with some interbedded gravel.

Stratified Drift - Stratified drift consists of fairly well sorted and layered sand and gravel that was deposited in contact with the glacial or by glacial streams.

Sand and Gravel, Undifferentiated - Sands and gravel that were not mapped as any particular type of landform were left as undifferentiated deposits.

Alluvium - These are well sorted deposits of silt, sand, and gravel forming banks and flood plains along rivers and streams.

Swamp Deposits - They are mainly silts, fine sands, and muck.

Artificial Fill - Fill material is usually taken from local sources of till or sand and gravel.

a. Planning Factors. Future planning and development of the study areas are governed to a large extent by topographic and geologic conditions. Foundation conditions are generally good in the glacial deposits. Normally, subsurface drainage within till areas is poor to fair, especially where the bedrock is near or at the ground surface. Subsurface drainage within sand and gravel deposits is normally good.

Landforms and the irregular coastline govern to a high degree the corridors available for transportation, utilities, and future expansion of existing communities. Patterns of community growth indicate a high degree of development in areas of glaciofluvial, outwash plains, stratified drift, undifferentiated sand and gravel deposits, partially due to the relative ease that man can work with and modify these materials. Low permeable soils in the hills and a frequent high groundwater level in the valleys make careful planning of liquid and solid waste disposal a necessity. Planning concepts should place a strong emphasis on the highly variable topography and subsurface materials throughout the area. Consideration of the areas situated in flood plains is a very important planning factor. For additional guidance in evaluating planning factors, see Plates 4-1 and 4-5 and Table 4-1.

b. Engineering Factors. Where designs are to be effective, careful consideration should be given to bearing capacity, and surface and groundwater conditions within the soil mass. Generally, bearing capacities of the soils in the basin are good, except for the highly compressible organic soils in swamps. Control of surface water during and after construction is a necessity in areas of low permeability soils. To avoid groundwater problems in proposed projects it is important that the groundwater level be monitored to aid in siting.

Glacial outwash deposits of unconsolidated gravel, sand, silt, clay, and mixtures thereof fill depressions in the underlying till and bedrock. These deposits are saturated with water to within a few feet of the land surface and form the principal aquifer in the study area. It is the

TABLE 4-1

SELECTED ENGINEERING CHARACTERISTICS OF SURFICIAL DEPOSITS

MATERIAL DESCRIPTION	THICKNESS OF DEPOSIT	EXCAVATION CHARACTERISTICS	BEARING CAPACITY (1)	AVERAGE NATURAL SLOPE	CUT SLOPES MAXIMUM	COMPRESSIBILITY AND EXPANSION	UNIT DRY WEIGHT (PCF)	EXCAVATION PERMEABILITY (GAL/DAY/CY)
Artificial fill-variable according to purpose	Variable	Easy to difficult	Poor to good, depending on material	Varies with material type	Varies with material type	Varies with land use	Variable	Unknown
Alluvium - silt, sand, and sometimes gravel	Variable to few tens of feet	Easy	Poor to fair (sandy) very poor to poor (silt and clay)	5^o	Stable to angle of repose. Require support below water table.	Negligible	Variable	50-1000
Till - unsorted mixture of clay, silt, sand, gravel and boulders. Generally compact and sometimes friable.	Variable, but generally less than 25 ft. thin on hill crests, thicker on lower slopes	Easy to difficult	Generally good.	25^o	0-15 feet = 90^o 15-40 feet = 28^o More than 40 feet from analysis	Negligible	100-135	1-35
Stratified drift-poorly to well sorted sand and gravel.	Variable to over 100 ft.	Easy	Fair (sand) to good (gravel)	5^o	Stable to angle of repose. Require support below water table.	Negligible to moderate	115-145	540-28800
Outwash plains - well sorted sand and gravel with lenses of coarser or finer material	Generally more than 25 ft.	Easy. Often requires dewatering before excavation	Fair (sand) to good (gravel). May settle with vibratory wading	5^o	Stable to angle of repose. Require support below water table.	Negligible to moderate	115-145	Often greater than 10000
Swamp deposits - silt, sand, clay with organic matter	Generally less than 15 ft.	Easy	Poor	2^o	Unstable. Flow readily into underwater excavations	Medium to high	90-130	1-20
Sand and gravel, undifferentiated	Variable to several tens of ft.	Easy	Fair (sand) to good (gravel)	5^o	Stable to angle of repose. Require support below water table.	Negligible to moderate	115-145	540-28800

1. Ranges of values for bearing capacity (TSF)

Very poor	Less than 1
Poor	1-4
Fair	4-8
Good	8-32
Excellent	Greater than 32

only aquifer capable of sustaining yields of 100 gallons per minute to individual wells. Further consideration of some engineering factors may be determined by comparison of Plates 4-1 and 4-5 and Table 4-1.

C. Construction Factors. Generally, excavation in the till areas is moderately difficult to difficult due to the relatively high soil density and presence of small to very large boulders. In addition, the bedrock is commonly near or at the ground surface which necessitates expensive rock excavation. Glaciofluvial deposits of sand and gravel on the plains and terraces normally provide the most desirable conditions for excavation. In areas where the groundwater table is high, especially near the shorelines of ponds, streams and the bay, undesirable construction conditions are often encountered. Underground utility construction conditions are generally good except in areas where the groundwater table is especially high or where dense till presents difficult excavating characteristics.

Adequate amounts of granular fill are readily available from the glaciofluvial and moraine deposits in the southern section of the study area. Generally, inadequate amounts of granular fill are available in the highly developed northern section and in the till areas of Aquidneck Island. Other construction factors in relation to the geology of the area are presented on Plates 4-1 and 4-5 and identified in Table 4-1.

C. BEDROCK GEOLOGY

1. Pawcatuck River Basin

Most of the basin is underlain by metamorphic rocks. Igneous rock occurs along the southern edge of the basin boundary and in small, scattered outcrops. Sedimentary rocks outcrop in one location along the southeastern boundary of the basin.

The metamorphic rocks are generally hard, foliated, highly jointed, and range in compressive strength from medium to very high. The igneous rocks have similar characteristics, but they are massive rather than foliated. All rock types exhibit slight weathering and high durability.

2. Narragansett Bay

Most of the Narragansett Bay study area is underlain by sedimentary rocks of the "Rhode Island Formation." This formation consists of sandstone, graywacke, shale, conglomerate, meta-anthracite and minor amounts of schist. Most of the remaining bedrock is igneous rock which occurs in the southwestern section of the study area. The igneous rocks are primarily composed of granite with lesser amounts of granite gneiss and are very hard, massive, and jointed. Compressive strength is medium to very high and weathering is slight. Relatively small isolated areas of metamorphic rock occur in the south central and southeastern sections of the bay area. The principal metamorphic rock types are mica schist and

meta-volcanics. These rock types are relatively hard, strongly foliated, and highly jointed. Compressive strength is variable from low for shale to high for sandstone. Generally weathering is thin, except for relatively thick zones of weathered shale occurring on Aquidneck Island.

Principal types of bedrock in the area are comprised of, but not limited to the following:

Gneiss - A medium to coarse grained, foliated, metamorphic rock composed of varying amounts of quartz, feldspar, mica with lesser amounts of magnetite and hornblende.

Amphibolite - A medium to coarse grained, foliated, metamorphic rock, composed of hornblende, feldspar, quartz, and mica.

Granite - A fine to coarse grained, massive to weakly foliated igneous rock composed of varying amounts of quartz, feldspar, and mica.

Sandstone - A fine to medium grained sedimentary rock composed chiefly of quartz.

Shale - A fine grained, laminated sedimentary rock composed chiefly of clay minerals.

Conglomerate - A coarse grained sedimentary rock composed of gravel and cobbles in a finer matrix.

a. Planning Factors. Due to their high strength and durability, the igneous rocks are desirable for use as a construction material; however, they are normally difficult to drill and excavate. Principal use of the granite is anticipated to be aggregates and protection stone for construction purposes. Metamorphic rocks are less desirable due to the tendency to break in flat and elongated sizes. The extensive sedimentary rock formation is the least desirable due to its tendency to disintegrate readily with handling and its undesirable flat particle shapes. Other planning factors related to bedrock can be evaluated by referring to Plates 4-2 and 4-6 and Table 4-2.

b. Engineering Factors. The igneous and metamorphic rocks in the area allow design based on medium to high compressive strength, slight weathering and good to excellent durability characteristics. The foliation in metamorphic rocks requires careful design of cut slopes, especially in mica schist. Slope stability in the igneous rock is excellent. The sedimentary rocks, due to the prominent bedding and jointing, require care in design of cut slopes to prevent extensive overbreak. Design for foundations bearing upon the sedimentary rocks are normally satisfactory for most purposes with care taken to evaluate weathered zones in areas of shale. Further application of engineering factors can be evaluated by using Plates 4-2 and 4-6 and Table 2.

TABLE 4-2
SELECTED ENGINEERING CHARACTERISTICS OF BEDROCK UNITS

ROCK TYPE	EXCAVATION CHARACTERISTICS	COMPRESSIVE STRENGTH	DRY UNIT WEIGHT (PCF)	DURABILITY	SURFACE BEARING CAPACITY (TSF-AVG)	YOUNG'S MODULUS OF ELASTICITY	EXCAVATION DIFICULTY	SOURCE OF CONSTRUCTION MATERIAL
Gneiss - medium to coarse grained, foliated	Directional stability. Moderately hard excavation. Shaping controlled by foliation.	Low to very high	162-176	Good to very good	40-100	Low to medium	Low to moderately high according to rock structure.	Fair to poor
Schist - fine to medium grained, foliated	Directional stability. Moderately hard excavation. Shaping controlled by foliation.	Low to medium	162-181	Good to very good	40	Low to medium	Low to moderately high depending on orientation of rock structure.	Fair to poor
Amphibolite - medium to coarse grained, foliated	Directional stability. Moderately hard excavation. Shaping contrl. by foliation.	Low to medium	162-181	Good to very good	40	Low to medium	Low to moderately high depending on orientation of rock structure.	Fair to poor
Quartzite - fine to medium grained, massive	Stability and shaping controlled by structure.	Medium to high	165-172	Very good	40	High	Moderately High	Good to fair
Granite - fine to coarse grained, massive to weakly foliated	Directional to uniform stability. Moderate to difficult excavation. Effective shaping except where controlled by foliation.	Medium to very high	162-173	Good to excellent	100	Low to medium	High	Good to excellent
Rhode Island formation - sandstone, graywacke, and shale	Directional stability.	Very low (shale) to high (sandstone).	135-162	Poor to good	15	Very low to low	Low	Poor

c. Construction Factors. Construction relating to bedrock within the basin largely depends on the position of the bedrock surface. Activity on the sides and tops of hills may encounter rock that normally presents high excavation difficulty with good slope stability. Within the valleys and plains it is doubtful whether construction activity will encounter the relatively deep bedrock surface. Of all the rock types, sedimentary rocks are the easiest of the three rock types to drill and excavate. Further evaluation of the bedrock formation in relationship to their construction characteristics can be evaluated by reference to Plates 4-2 and 4-6 and Table 2.

D. SEISMIC ACTIVITY

One large fault is mapped in the southwestern section of the area. There is no information on displacement; however, the fault is not considered active.

The study area lies in Zone 1 of the seismic risk map of the United States. Zone 1 is classified as having potential for minor damage from earthquakes with corresponding maximum intensities of V and VI of the 1931 modified Mercalli scale. Epicenters with corresponding intensities in the range of III to VI have been indicated for the Rhode Island-Connecticut area. The seismic potential of earthquakes with epicenters in western Rhode Island and eastern Connecticut, as well as in the surrounding vicinity, should be evaluated and appropriate factors applied to designs for construction.

WOONASQUATUCKET

Surficial Geology - Unconsolidated deposits mantle the bedrock surface to varying degrees throughout the basins. The thinnest surface cover and hence, the greatest exposure of bedrock, is evident on the sides and tops of the low hills in the central and northern sections of the basin, which encompass the towns of Smithfield, Lincoln and Glocester. Surficial deposits are primarily derived from glacial action. Postglacial deposits are minor and occur as alluvium and swamp deposits near streams and blocked drainage areas on hills. Principal glacial deposits (see Plate 4-3) are chiefly comprised of glacial till and glaciofluvial deposits.

Glacial till, an unsorted, compact, low permeability material, underlies most of the glaciofluvial unconsolidated deposits and also forms the irregular hills. Thin deposits of till occur as a veneer over the bedrock surface in the higher elevations. Till in this area is comprised of varying amounts of silt, sand, gravel and boulders.

Glaciofluvial deposits of sand and gravel in the valleys are normally the most desirable for modification in construction projects. Other planning, engineering and construction factors in relation to the geology of the area are depicted on Plate 4-3 and Tables 4-3 through 4-5.

Bedrock Geology - The basin is underlain by a nearly even proportion of igneous and metamorphic rocks with a lesser amount of sedimentary rock. The igneous rocks include granite, gabbro and granodiorite. The metamorphic rocks include gneiss, schist and greenstone. Sedimentary rocks occurring in the basin are sandstone, shale and conglomerate. Generally, the metamorphic rocks occur in the western and southern sections of the basin, the igneous rocks occur in the center area, and sedimentary rocks occur along the eastern edge and a smaller area in the southwestern section. Generally, the igneous rocks are hard, dense, massive and of a high compressive strength. The metamorphic rocks are hard, foliated and range in compressive strength from low to high, while the sedimentary rocks are generally of low to medium compressive strength and exposures are less frequent than the other rock types.

Planning Factors - High strength igneous rock types are desirable as a construction material. However, they are normally difficult to excavate. The igneous rocks comprise about 40 percent of the area. Metamorphic rocks make up about another 40 percent of the area and are less difficult to excavate, depending upon orientation of the foliation. Sedimentary rocks make up the remaining 20 percent and the types present are usually unsuitable for construction purposes as dimension stone. Future utilization of the bedrock resources in the basin may be anticipated in the igneous rock area. Principal use of the igneous rock is anticipated to be aggregates for construction purposes. Other factors related to bedrock can be evaluated by referring to Plate4-4 and Table 4-6.

Engineering Factors - The predominant igneous and metamorphic rocks in the basin allow design utilizing the high compressive strength, slight weathering and good to excellent durability characteristics. The foliation in metamorphic rocks require care in design of cut slopes. The sedimentary rocks, although less dense, normally provide sufficient strength and durability for most construction purposes. The conglomerate formations present irregular and usually somewhat difficult characteristics for excavation. Further application of engineering factors can be evaluated by reference to Plate 4-4 and Table 4-7.

Construction Factors - Construction in the basin is largely influenced by the igneous and metamorphic rocks which have the general characteristics of high strength, durability and shallow depths to the bedrock surface. Excavation difficulty is generally high with good slope stability. The sedimentary rocks are somewhat easier to excavate, except for the conglomerate, and all have generally good slope stability characteristics. The sedimentary rock formation surface is usually deeper than the other rock types and may not be encountered in most construction projects. Further evaluation of the bedrock formations in relationship to their construction characteristics can be evaluated by reference to Plate 4-4 and Table 4-8.

TABLE 4-3

SELECTED ENGINEERING CHARACTERISTICS OF SURFICIAL GEOLOGY

PLANNING FACTORS

Type of Deposit	Topographic Utilization	Best Land Use	Surface Drainage	Runoff Rate	Subsurface Drainage	WASTE DISPOSAL Solid	WASTE DISPOSAL Liquid	HAZARDS Landslide Susceptibility	HAZARDS Vibration Potential	HAZARDS Earthquake Effects
Glacial Till	Private Homes, High Rise, Hiking Trails	Suburban Recreation	Good	High	Poor to Fair	Poor to Fair	Poor to Limited	None	Minimal	Slight
Glacio-fluvial Deposits	Highways, Railroads, Airports, Home Construction, Suburban Centers, Industrial Dev., Farming	Urban, Commercial Development, Agriculture, Recreation	Good to Limited	Medium to Low	Good	Good to Limited by Drainage Pattern	Good to Limited by Water Table	None	Moderate to High	Slight to Moderate
Swamp and Marsh Deposits	Flood Storage, Conservation, Limited Commercial Uses, Utility Corridors	Conservation, Specialized Commercial Uses	Poor	Low	Poor	Poor to Limited Depending on Drainage	Poor	None	High	High

TABLE 4-4

SELECTED ENGINEERING CHARACTERISTICS OF SURFICIAL GEOLOGY

ENGINEERING FACTORS

Type of Deposit	Material Description	Thickness of Deposit	Drainage Characteristics	Excavation Characteristics	Bearing Capacity	Frost Susceptibility	Average Slope (Deg) (Natural)	Cut Slopes Max. (Deg)	Compressibility & Expansion	Unit Dry Weight LB./C.F.	Excavation Permeability Gal/Day/Sy
Glacial Till	Unsorted mixture of clay, silt, sand, gravel and boulders	Average less than 25'. Thin to absent on tops of hills thickening to 50' on lower slopes. Streamlined hills may be 150' thick	Fair to Poor	Mod. hard to difficult	Good	High	25^{o}	0-15'=90^{o} 15-40'=28^{o} =2:1 40' =by Design	Very slight	100-135	1-35
Glacio-fluvial Deposits	Stratified sand and gravel w/ some silt	Generally less than 125'. In small valleys commonly less than 40'.	Good to Excellent	Little difficulty	Fair to Good Vibratory loading may cause settlement	None to slight	5^{o}	Cut slopes stable to angle of repose	None	115-145	540-28,000
Swamp and marsh deposits	Silt, sand clay and organic material	Generally shallow up to 15'	Poor	Easy	Poor	Medium to high	$0-2^{o}$	Poor, unstable, flows readily into underwater excavation	Medium to high	90-130	1-20

TABLE 4-5

SELECTED ENGINEERING CHARACTERISTICS OF SURFICIAL GEOLOGY

CONSTRUCTION FACTORS

	TRANSPORTATION CORRIDORS		UTILITY CONSTRUCTION		BUILDING CONSTRUCTION			
Type of Deposit	Above Ground	Below Ground	Above Ground	Below Ground	High Rise	Commercial Buildings	Private Homes	Source of Construction Materials
Glacial Till	Poor	Good	Good	Difficult with High Cost	Good to Moderately Good	Poor	Good	Moderately Favorable
Glaciofluvial Deposits	Good	Poor to Moderately good depending on water table	Good to Moderately Difficult	Easy to Moderately Difficult with least expense	Good to Moderately Difficult	Good	Good with Limitations Depending on Water Table	Highly Favorable
Swamp and Marsh Deposits	Good Limited by low bearing	Poor	Poor to moderately good depends on loading	Difficult with moderate expense	Poor to limited depending on design	Poor to limited depending on design	Poor	Limited to specialized uses

TABLE 4-6

SELECTED ENGINEERING CHARACTERISTICS OF BEDROCK GEOLOGY

PLANNING FACTORS

Type of Deposit	Topographic Representation	Surface Excavation Difficulty	Well Development Potential	Control Of Cut Slopes	TUNNEL FEASIBILITY		HAZARDS		Potential Quarry Operations
					Machine	Conventional	Rock Slopes Stability	Quarries	
Igneous	High relief and frequent surface exposure	High	Poor	Good	Poor to good	Good to excellent	Good to excellent	Large and numerous	High
Metamorphic	Moderate relief and numerous surface exposure	Low to High	Fair	Poor to Good	Excellent	Good to excellent	Poor to good	Small and limited	Limited to specialized uses
Sedimentary	Low relief with infrequent exposures	Low	Good	Good	Good to excellent	Good	Poor to Good	Limited	Poor

TABLE 4-7

SELECTED ENGINEERING CHARACTERISTICS OF BEDROCK GEOLOGY

ENGINEERING FACTORS

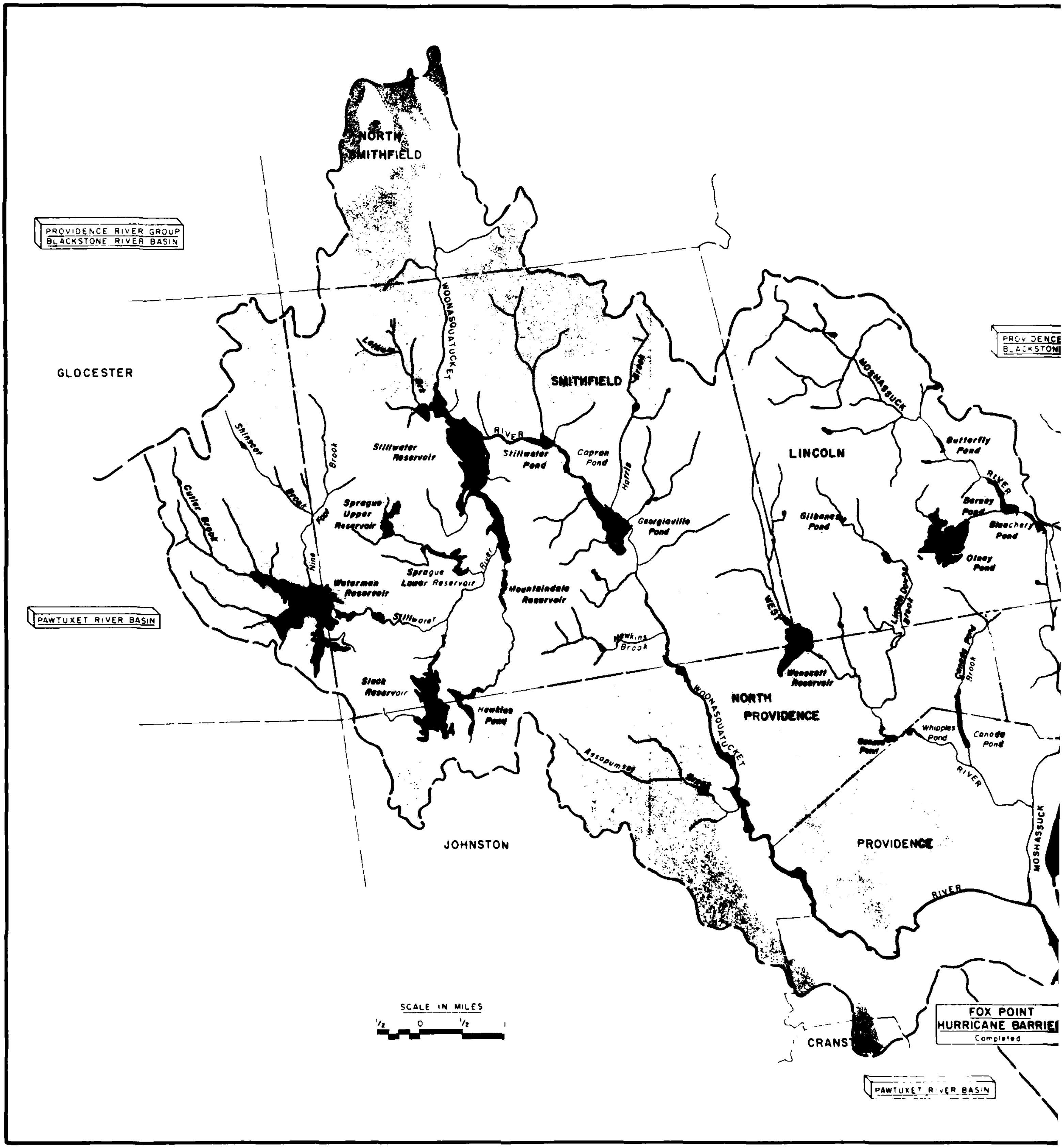
Type of Deposit	Material Description	Excavation Characteristics	Compressive Strength P.S.I.	Dry Unit Weight LB / c.f.	Durability	Depth of Weathering	Youngs Modulus of Elasticity	Slope Stability	Surface Bearing Capacity (Avg) T.S. F.	Permeability Yield of Wells Median Range G.P. M.
Igneous	Hard to very hard, massive, glassy to granular texture wi.h interlocking grains	Uniform stability difficult excavation effective shaping	High to very high	162 to 173	Good to excellent	Slight	Low to very high	Good to Excellent	100	6-12
Metamorphic	Moderate, hard to very hard, banded, distorted with parallelish of interlocking grains	Directional stability mod. hard excavation shaping controlled by foliation	Low to high	170 to 195	Good to very good	Shallow except to greater depths along foliation planes	Low to high	Good to very good	40	9-15
Sedimentary	Soft to moderately hard stratified rounded and sorted grains fine to course texture	Directional stability, east excavation shaping highly dependent on stratification	Low to medium	155 to 170	Poor to good	Slight except for deeply weathered zones	Very low to high	Poor to good	25	10-25

TABLE 4-8

SELECTED ENGINEERING CHARACTERISTICS OF BEDROCK GEOLOGY

CONSTRUCTION FACTORS

	UNDERGROUND EXCAVATION METHODS		SURFICIAL EXCAVATIONS				
Type of Deposit	Machine Excavation	Conventional Excavation	Utility Locations	Drill and Blast Methods	Mechanical Methods	Excavation Difficulty	Source of Construction Materials
Igneous	Poor to Good	Good	Poor, Rock is generally shallow and most difficult to excavate	Most Rapid Least Expensive	Slow, Highly Expensive	High	Good to Excellent
Metamorphic	Good to Excellent	Poor to Good	Poor to Good Limited surface exposures, moderately difficult to excavate	Normally Least Expensive	Effectiveness dependent on rock structure	Low to Moderately high depending on orientation of rock structure	Fair to Poor
Sedimentary	Good to Excellent	Poor to Good	Good to Excellent Rock is deeply buried and least difficult to excavate	Cost dependent on size and shape of excavation	Least expensive for large shallow excavation	Low	Poor



NORTH SMITHFIELD
PROVIDENCE RIVER GROUP
BLACKSTONE RIVER BASIN
GLOCESTER
SMITHFIELD
LINCOLN
WOONASQUATUCKET
RIVER
Stillwater Reservoir
Stillwater Pond
Capron Pond
Harris
Georgiaville Pond
Sprague Upper Reservoir
Sprague Lower Reservoir
Waterman Reservoir
Mountaindale Reservoir
Stillwater
Slack Reservoir
Hawkins Pond
Hawkins Brook
Nine Foot
Brook
Shinscot
Cutler Brook
PAWTUXET RIVER BASIN
JOHNSTON
NORTH PROVIDENCE
Wenscott Reservoir
WEST
Assapumset
MOSHASSUCK
Butterfly Pond
Barney Pond
Blackstone Pond
Olney Pond
Gilbane Pond
Whipples Pond
Canada Pond
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PROVIDENCE
SCALE IN MILES
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HURRICANE BARRIE
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PAWTUKET RIVER BASIN

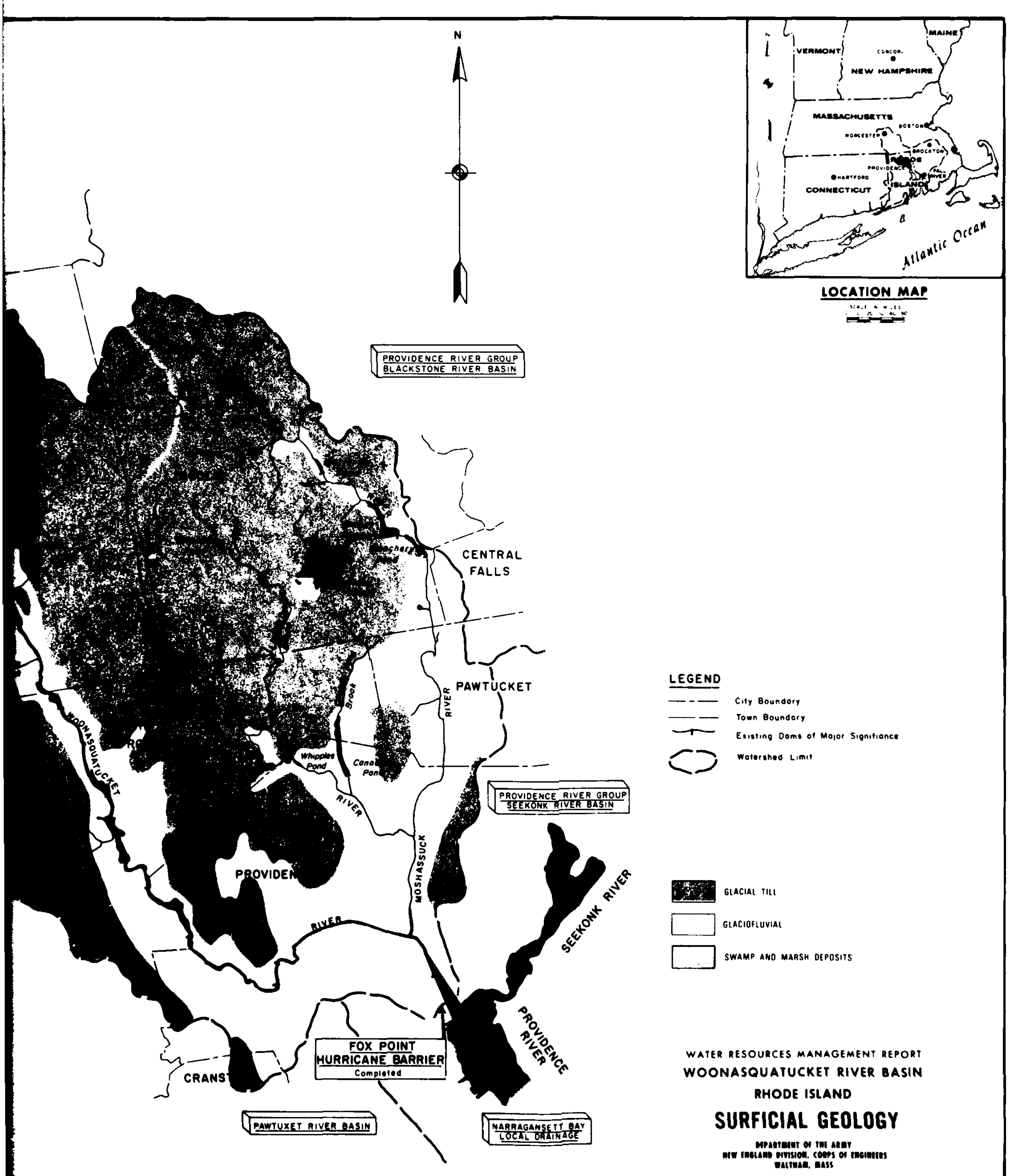
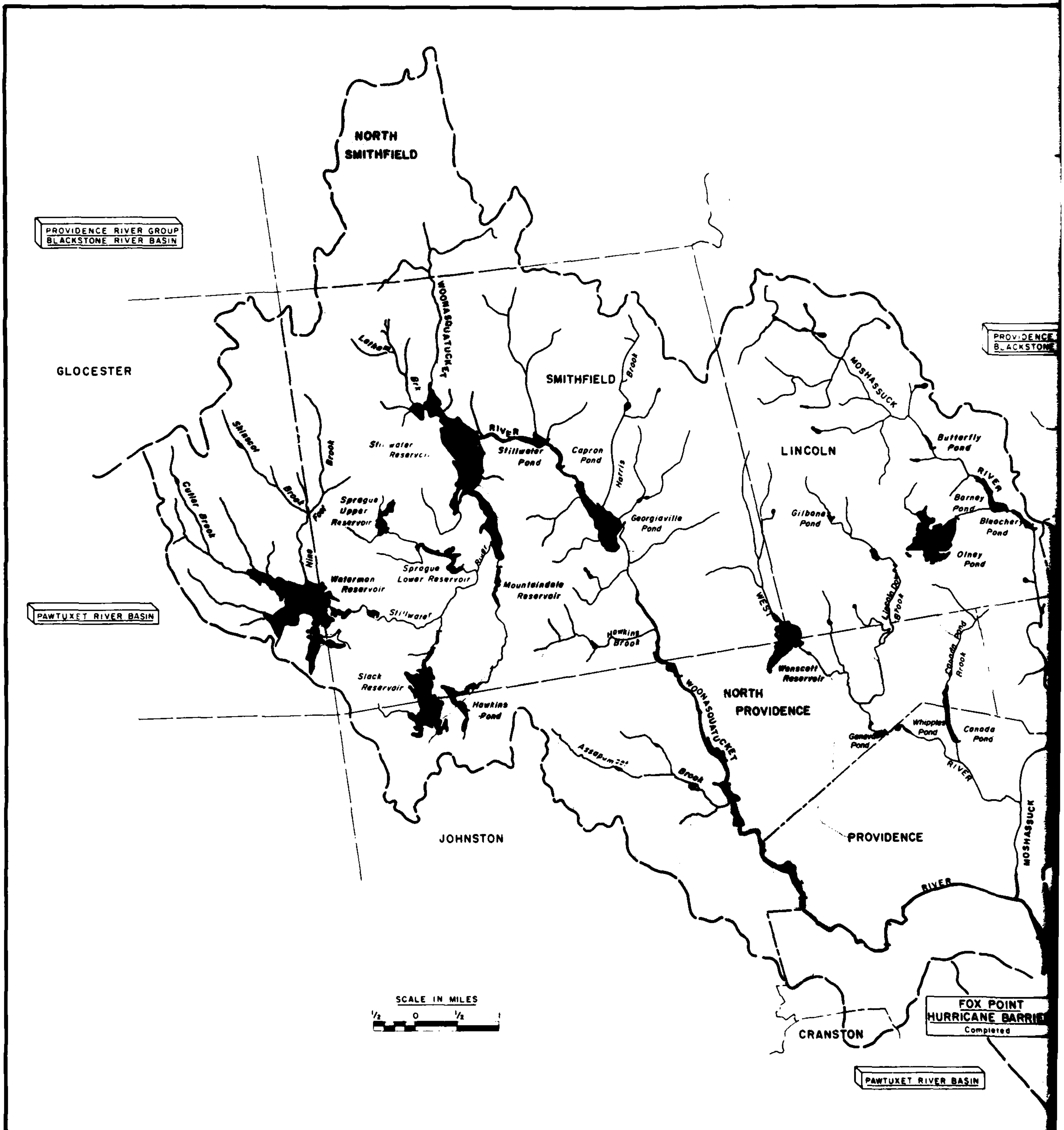
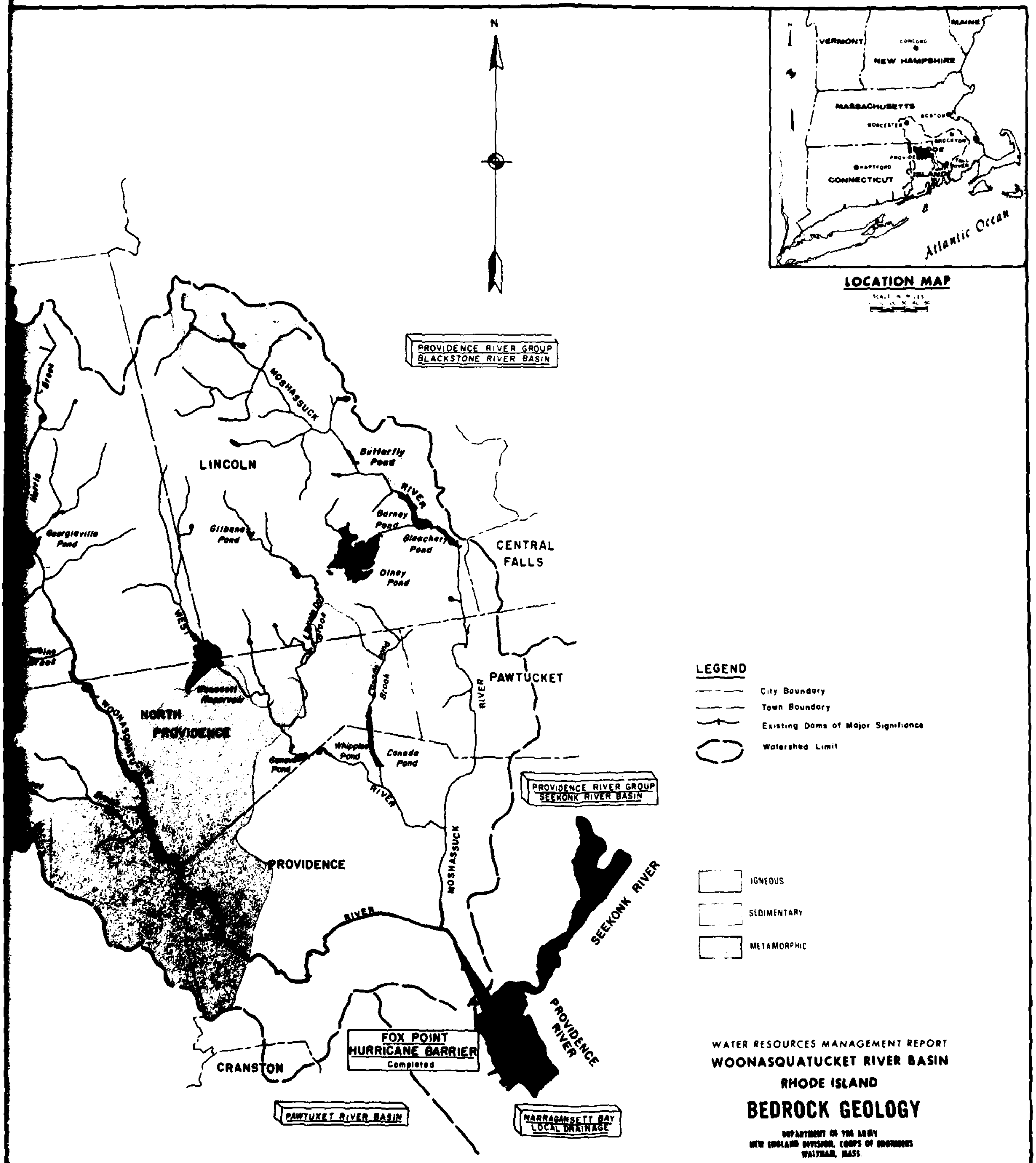

N
VERMONT
NEW HAMPSHIRE
MAINE
MASSACHUSETTS
BOSTON
WORCESTER
BROCKTON
PROVIDENCE
FALL RIVER
HARTFORD
CONNECTICUT
RHODE ISLAND
Atlantic Ocean
LOCATION MAP
PROVIDENCE RIVER GROUP
BLACKSTONE RIVER BASIN
CENTRAL FALLS
PAWTUCKET
RIVER
Brook
Whipples Pond
Canada Pond
RIVER
WOONASQUATUCKET
PROVIDENCE RIVER GROUP
SEEKONK RIVER BASIN
MOSHASSUCK
PROVIDEN
RIVER
SEEKONK RIVER
PROVIDENCE RIVER
FOX POINT
HURRICANE BARRIER
Completed
CRANST
PAWTUXET RIVER BASIN
NARRAGANSETT BAY
LOCAL DRAINAGE
LEGEND
City Boundary
Town Boundary
Existing Dams of Major Significance
Watershed Limit
GLACIAL TILL
GLACIOFLUVIAL
SWAMP AND MARSH DEPOSITS
WATER RESOURCES MANAGEMENT REPORT
WOONASQUATUCKET RIVER BASIN
RHODE ISLAND
SURFICIAL GEOLOGY
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS

PLATE 4


NORTH SMITHFIELD
PROVIDENCE RIVER GROUP
BLACKSTONE RIVER BASIN
GLOCESTER
SMITHFIELD
WOONASQUATUCKET
RIVER
Stillwater Pond
Capron Pond
Georgiaville Pond
Waterman Reservoir
Sprague Upper Reservoir
Sprague Lower Reservoir
Mountaindale Reservoir
Slack Reservoir
Hawkins Pond
Hawkins Brook
LINCOLN
MOSHASSUCK
Butterfly Pond
Barney Pond
Bleachery Pond
Olney Pond
Gilbane Pond
Wenscott Reservoir
NORTH PROVIDENCE
Whipples Pond
Canada Pond
Geneva Pond
PAWTUXET RIVER BASIN
JOHNSTON
PROVIDENCE
RIVER
CRANSTON
SCALE IN MILES
FOX POINT
Completed
PAWTUXET RIVER BASIN



WATER RESOURCES MANAGEMENT REPORT
WOONASQUATUCKET RIVER BASIN
RHODE ISLAND

BEDROCK GEOLOGY

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.

PLATE 4-4

Mineral Resources - Sand and gravel deposits are common in the river valleys. However, there are no major producers of sand and gravel materials. Local borrow of sand and gravel and fill is primarily for use as road material or fill. At one time, granites quarried from the area of Esmond and Graniteville supplied dimension stone. There are several abandoned quarries. Also, there were a few early prospects for metals which proved unsuccessful.

Presently there is limited commercial utilization of mineral resources within the basin. Limestone and marble are locally mined in an area several miles northwest of Pawtucket. The lime materials are generally dolomitic and the products are made for agricultural use.

Crushed stone is obtained on a small scale from a number of rock types for use as road material.

NARRAGANSETT BAY

A preliminary study of six local protection projects in the Narragansett Bay area was completed by Allinson, Inc. in June 1977. The project description portion has been included in this report followed by a similar report done by C.E. Maguire on the Seekonk River local protection project.

Also included in this section are summary tables showing the benefits, costs, and benefit-to-cost ratios of each of these projects.

SITE 01

The protected areas of Site 01 are located in three Rhode Island communities; the city of Warwick, the town of East Greenwich, and the town of North Kingstown. Major protective structures for this site are the "Greenwich Bay hurricane barrier" and the "Old Mill Creek dike."

The southern terminus of the Greenwich Bay barrier is at a point 1500 feet (more or less) west of Pojac Point on the south bank of the Potowomut River. Proceeding northeasterly for a distance of 10,185 feet, the barrier crosses the mouth of the Potowomut River, and the mouth of Greenwich Bay. Barrier landfall at the northerly end is adjacent to the buildings of the Warwick Country Club 1000 feet south of Narragansett Bay Avenue in the city of Warwick. A 75 foot navigational gate is located 1600 feet from the northerly terminus. The major bodies of water behind the proposed Greenwich Bay Barrier are the Potowomut River and Greenwich Bay with its attendant coves, Greenwich, Apponaug, Buttonwoods, Brushneck, and Warwick.

The Old Mill Dike has its beginnings at a point 150 feet northwest of the Tidewater Drive, Mill Cove Road intersection in the city of Warwick. This dike is entirely land based and entirely in the city of Warwick. The dike crosses West Shore Road at a right angle and runs northwesterly, parallel and 400 feet northeasterly of Church Avenue to a point 400 feet of the Church Avenue, Overbrook Avenue intersection. At this point the dike turns southwesterly, crosses Church Avenue and proceeds 150 feet to the northerly terminus.

The protected land area consists of the areas immediately adjacent to the shoreline. Major intrusions beyond the shore line occur at the end of Potowomut Neck, in Apponaug, in Oakland Beach, and along Warner, Knowles and Buckeye Brooks. Total protected land area is 2899.6 acres. Predominate land uses are residential and marina facilities with industrial areas in Apponaug. Greenwich Bay and its radiating coves is a major Rhode Island marine recreational area. Sailing, fishing, bathing and shellfishing are all important facets of the recreational scene.

SITE 02 ALTERNATIVE "A" AND ALTERNATIVE "B"

The protected areas of this site are identical for Alternative "A" and Alternative "B". Differentiation between alternatives indicates the relationship of this site to SITE 03. SITE 02 Alternative "A" is an independent site which provides protection without the construction of SITE 03. SITE 02 Alternative "B" is dependent upon the construction of SITE 03. This dependence arises from the elimination of 4 dikes on the west shore of the Barrington River. As the protected areas are equivalent for both alternatives, the descriptions are combined.

The protected areas of SITE 02 lie in four Rhode Island Communities east of Narragansett Bay, the city of East Providence, and the towns of Barrington, Warren, and Bristol; and in three Massachusetts towns, Seekonk, Swansea, and Rehoboth. Major protective structures for this site are the Rumstick Neck Barrier with associated dikes "C", "D", "E", and "F", and the Kickamuit River Barrier with associated dikes "A" and "B". SITE 02 Alternative "B" differs only in the elimination of dike "C", "D", "E", and "F". The Rumstick Neck Barrier begins 1400 feet north of Beach Road and 250 feet east of the easterly shore of the Warren River in the town of Bristol. Proceeding west-northwesterly the barrier crosses the mouth of the Warren River then turns northerly along the westerly shore of Rumstick Neck in the town of Barrington. At a point 660 feet north of Holly Lane the barrier turns eastward and runs inland to within 230 feet of Rumstick Road where the barrier ends. Four dikes are required in the town of Barrington along the Barrington River west bank for SITE 02 Alternative "A". Dike "C" is the northmost dike located 200 feet southeast of Winsor and Manning Drives. This dike extends 450 feet in a southwesterly direction, crossing a small creek. Dikes "D, "E", and "F" are south of dike "C" with dike "F" being the most southerly. Dike "D" is located 400 feet due east of the Barrington town hall. Proceeding 500 feet easterly, dike "D" ends at Riverside Drive. Beginning 400 feet southwest of dike "D", dike "E" crosses the intersection of Riverside Drive and Stratford Road. Four hundred fifty feet long, dike "E" ends between Stratford and Fairway roads. Dike "F" runs north-south 150 feet crossing a set of railroad tracks between Foster and Surrey Roads.

The Kickamuit Barrier, athwart the Kickamuit River at Bristol Narrows, stretches 810 feet between the town of Bristol and the town of Warren. Harrison Avenue, Bristol is the location of the barrier's westerly end. The easterly end of the barrier is 200 feet west of Emery Road, Warren. Two dikes are required east of the Kickamuit River in the town of Warren to complete the protection project. Dike "A" is located 1800 feet east of Bristol Narrows. The starting point of dike "A" is just north of the Touisset Road, Bayview Avenue intersection. Situated to the north of Touisset Road, dike "A" runs 300 feet easterly to its end where the road turns northward. Dike "B" commences 700 feet north of dike "A". Continuing northly 600 feet along the west side of Touisset Road, dike "B" ends 780 feet south of Maple Road. Dikes "A" and "B" are included in both Alternative "A" and Alternative "B" for SITE 02.

The major water bodies behind the Rumstick Barrier reach northward from Rumstick Point into Massachusetts as an elongated 'Y'. The base is formed by the Warren River, while the Palmer River extends into Rehoboth, Massachusetts as the east arm. Leaving the Palmer River, Warren River confluence, the Barrington River reaches northward as the west arm. At the Providence County line the Barrington River diminishes greatly in size and is renamed the Running River. This river forms the boundary between Rhode Island and Massachusetts, and reaches to Burrs Pond in Seekonk. Behind the Kickamuit Barrier the Kickamuit River extends northward into Warren, Rhode Island. That portion of the Kickamuit River, north of Child Street in Warren is known as the Warren Reservoir. The Bristol County Water Company uses the reservoir as a water source. Heath Brook extends from the reservoir to U.S. 6 in Swansea, Massachusetts.

Area protected by this hurricane protection plan is extensive. Combined land area behind the two major barriers and six dikes is 8104.2 acres. This is the largest protected area of any individual site analyzed by this study. Along the Warren, Palmer, Barrington River system the protected areas suitable for development are heavily residential. Commercial, service and institutional land uses are interspersed throughout the areas. Industrial uses are located along the east bank of the Warren River and other scattered locations. There are large areas of undeveloped land such as swamps and tidal flats. In Massachusetts the protected areas are largely rural in nature with sparse development. The protected area surrounding the Kickamuit River is lightly developed; the exception, however, is the west bank. The limits of the protected area closely follow the shore line of the Kickamuit River. Areas adjacent to the Warren River and Heath Brook are more expensive but are sparsely developed.

SITE 03 ALTERNATIVE "A"

The area protected by SITE 03 Alternative "A" (SITE 03A) entails portions of two Rhode Island communities to the east of the Providence River, the city of East Providence and the town of Barrington. Proposed hurricane protection elements at this site are the "Bullock Cove Barrier" and two minor dikes known as dike "A" and dike "B." The Bullock Cove Barrier, 9890 feet in length, begins at the junction of Washington Road and Echo Drive in the town of Barrington. Pushing southwesterly the barrier reaches the east shore of the Providence River and turns northwesterly along the river shore. At the mouth of Bullock cove the barrier proceeds westerly entering East Providence, and continues to the west side of Bullock Point. Heading northerly the barrier skirts Bullock Neck and terminates at a point 260 feet northwest of Terrace and Channing Avenues in East Providence. There is a 50 foot navigational gate at the entrance to Bullock Cove. Dike "A" and dike "B" are both located near the southern terminus of the Bullock Cove Barrier in the town of Barrington. These dikes will prevent flooding from the Mussachuck Creek, Echo Lake area. One hundred fifty feet long, dike "A" is situated east of Northlake Drive and North Lake Lane, and crosses Northlake Drive. Dike "B" will be

constructed 300 feet northeast of dike "A," and perpendicular to the railroad and Pine Cone Drive. The dikes northeasterly end is midway between Houghton Street and Joann Drive.

Bullock Cove and Drown Cove are the principal bodies of water behind the Bullock Cove Barrier. The protected areas behind this barrier consist of the southerly and easterly portions of Bullock Neck, other portions of East Providence adjacent to the town line, Allen Neck, and Annawomscutt in Bristol. Major intrusion inland occurs to the east of Bullock Cove. Those areas which closely trace the shoreline are sparsely developed due to the proximity of the water. Where the protected area is more spacious it is more fully developed with residential land use and its appurtenant services and retailing predominating. Industrial development flanks the railroad which runs northwest-southeast through the area. Bullock Cove shelters three large marinas and numerous pleasure crafts. Total protected land area for SITE 03 Alternative "A" is 535.2 acres.

SITE 03 ALTERNATIVE "B"

The protected areas of SITE 03 Alternative "B" (SITE 03B) are essentially identical to those of SITE 03 Alternative "A" (SITE 03A). SITE 03B contains all areas included in SITE 03A plus an additional area surrounding Echo Lake, Mussachuck Creek, and Brickyard Pond. This additional area is 956.2 acres, increasing the total protected land area for SITE 03B to 1491.4 acres. Protection for this supplementary area is achieved by the southward extension of the Bullock Cove Barrier beyond its termination at Washington Road and Echo Drive in Barrington. Alternative "B" barrier alignment commences 2600 feet south of Alternative "A." Starting 300 feet north of Glen Avenue and Dexter Street near Nayatt Point in Barrington, Alternative "B" runs north-northwest along the east shore of the Providence River. The barrier crosses Mussachuck Creek and joins Alternative "A" alignment at a point 1000 feet west of Washington Road and Tallwood Drive. Turning northwesterly the Alternative "B" alignment is identical to that of Alternative "A." Total barrier length for SITE 03 Alternative "B" is proposed in conjunction with SITE 02 Alternative "B" and is dependent upon the construction of SITE 02B.

All areas of SITE 03B are described in the discussion of SITE 03A, except that area behind the extended barrier across Mussachuck Creek. Principal water bodies behind the added barrier length are Echo Lake, and Brickyard Pond. The protected area stretches eastward between the railroad and Nayatt Road to the Barrington River, and northward along Middle Highway to Federal Road. Significant areas are occupied by ponds and swamp lands. Developed areas are dominated by individual dwellings. Schools and country clubs are important special land uses.

SITE 02 ALTERNATIVE "B" AND SITE 03 ALTERNATIVE "B"

All protected areas, and barrier locations for the combined SITE 02 Alternative "B" and SITE 03 Alternative "B" (SITE 02B & 03B) are described

in the discussions for SITE 02 Alternative "A" and Alternative "B" and SITE 03 Alternative "B." Implementing the hurricane protection plans for SITE 02B and SITE 03B as a dependent pair produces economies due to dike elimination. Construction of the SITE 03B barrier across Mussachuck Creek serves the function of four dikes required by SITE 02 Alternative "A" along the west bank of the Barrington River. Specifically the dikes eliminated from SITE 02 Alternative "A" are; dike "C", dike "D", dike "E", and dike "F". Dike "A" and dike "B" east of the Kickamuit River for SITE 02 Alternative "A" will be required for the combined SITE 02B and 03B. Detailed locations for these dikes are given in the appropriate site discussions. Total protected land area for the combined SITES 02 Alternative "B" and 03 Alternative "B" is 9595.6 acres.

SITE 04

The protected areas of SITE 04 are located in three Rhode Island communities, to the west of Narragansett Bay. Flanking the Pettaquamscutt River, these communities are, the town of Narragansett, the town of South Kingstown, and the town of North Kingstown. Two major protective structures for this site are located northwest of Narragasett Beach between Narragansett Pier and Cormorant Point in the town of Narragansett. The Narrows Barrier runs parallel to and southeasterly of Boston Neck Road (Route U.S. 1A) as it crosses The Narrows. Beginning 300 feet east of Boston Neck Road this barrier reaches 1345 feet northeasterly across the Narrows and ends 850 feet south of Old Boston Neck Road. The Little Neck Dike is situated 1900 feet southwest of the Narrows Barrier, and west of Boston Neck Road. The southerly end of the dike is 450 feet northeast of northerly end of Strathmore Road. Proceeding northeasterly for 1350 feet the dike crosses northwest of Little Neck Pond and terminates 100 feet south of South Trail and Wood Avenue. This barrier is 1000 feet northwesterly and parallel to Boston Neck Road in front of Narragansett Beach.

Major water bodies behind the protective structures are, Pettaquamscutt Cove, Pettaquamscutt River and Carr Pond. The protected area lies between Tower Hill Road (U.S. 1) and Boston Neck Road (U.S. 1A) and stretches from the US 1-US 1A junction northward to the R.I. route 138 Jamestown Bridge connection. Total protected land area for SITE 04 is 1296.5 acres. Major developed areas in the protected area, which closely follows the Pettaquamscutt River shore line, is between Bridge Road and the North Kingstown line. Residential land use predominates. South of Bridge Road, surrounding Pettaquamscutt Cove are large areas of undevelopable swamp land. Fishing and shellfishing are important recreational activities in the protected area.

SITE 05

Areas protected by implementation of the proposed hurricane protection plan for this site fall entirely within the town of North Kingstown. Wickford Harbor, on the west shore of Narragansett Bay, is

the center of the protected areas. The Wickford Harbor Barrier has its southerly terminus 850 feet north of Elm Drive and 1400 feet east of Boston Neck Road, south of the village of Wickford. Proceeding north northwesterly the barrier runs along Cold Spring Beach to Beach Street. North of Beach Street the barrier begins a swing to the north east running along the shore line to Poplar Point, at the southerly end of the existing breakwater. Again turning northerly the barrier runs atop the existing breakwater to Sauga Point. From Sauga Point the barrier proceeds north-easterly along the shoreline, easterly of Shore Acres, to a point on the former Quonset Naval Air Station, 980 feet east of 6th and Middle Streets. Total length of the barrier is 9300 feet.

Wickford Harbor, Wickford Cove, Mill Cove, Mill Creek, and Fishing Cove are the major water bodies and inlets behind the Wickford Harbor Barrier. The protected area lies generally east of Tower Hill Road (U.S. 1). Bounded to the north by the Quonset Access Road and to the south by Annaquatucket Road and Prospect Avenue, the protected area is roughly rectangular in shape. Total protected land area is 999.5 acres. Included in the protected land is the historic village of Wickford, and new developments to the south of Quonset Point. Commercial, retail, and marine facilities are the major land uses in Wickford, while residential land use preponderates elsewhere.

SITE 06

Two Aquidneck Island communities share the area protected by the proposed barrier at SITE 06. The Easton Beach Barrier is 5000 feet long, reaching from the city of Newport to the town of Middletown. SITE 06 is located east of Narragansett Bay and is directly exposed to the Atlantic Ocean. Hurricane protection at this site consists of one barrier running along Easton Beach. The western starting point of the Easton Beach Barrier is 300 feet northeast of Memorial Boulevard and Eustic Avenue in the city of Newport. From this point the barrier proceeds generally northeasterly, adjacent to and northwesterly of Memorial Boulevard. At the easterly shore of Easton Pond the barrier swings northward, running along the easterly shore of Easton Pond. On this northward course the barrier is 250 feet west of, and parallel to Aquidneck Avenue. Three hundred feet south southwesterly of Aquidneck Avenue and Valley Road in Middletown, the barrier ends.

The major bodies of water behind the hurricane barrier are Easton Pond and Green End Pond. From Easton Beach the protected area extends northward to a point 2000 feet north of Green End Avenue in Middletown. Those protected areas within the city of Newport are residential in nature. The protected areas in Middletown are rural in nature. Side slopes of the protected area are relatively steep thus limiting the protected area to those areas very close to the shore lines of the ponds. With 210.4 acres the total protected land area is the smallest of any site analyzed during this study. Green End Pond forms the water supply for the city of Newport.

RECONNAISSANCE REPORT
LOCAL PROTECTION PROJECT
SEEKONK RIVER
EAST PROVIDENCE, RHODE ISLAND

1. Authority.

This study is being conducted under contract with the New England Division U.S. Army Corps of Engineers in compliance with regulations adopted by the Committees on Public Works, the United States Senate and House of Representatives in 1968 and 1970.

2. Area Description.

The area of study discussed in this reconnaissance report is located on the bank of the Seekonk River in the Phillipsdale section of East Providence, Rhode Island. The project site lies just upstream from the confluence of the Seekonk River and the Ten Mile River, between Greenwood Point and Bucklin Point. The Ten Mile River flows through Southeastern Massachusetts a distance of approximately 20 miles and drains an area of 54 square miles before it discharges into the tidal section of the Blackstone River called the Seekonk River. The Seekonk River at the project site has a contributary basin of 540 square miles extending from its headwaters near Worcester, Massachusetts, approximately 46 miles to tidewater.

The project site lies in Providence County in the northwest area of East Providence, Rhode Island, and is bounded on the west by the Seekonk River, in the north by the Bucklin Point Sewage Treatment Facility, on the east by trackage of the Providence and Worcester Railroad, and in the south by Omega Pond and the outlet of the Ten Mile River. The site, approximately 80 acres, is about 60 percent developed, supporting three industrial complexes; the Washburn Wire Company, the Okonite Company, and the warehousing and distribution facilities of the Almacs Company. Access and service to the site is gained by Bourne Avenue and the railroad on the east and the 16 foot shipping channel on the west. The topography is relatively flat and low lying ranging from grades at the river bank of 6.0 feet to approximately 25.0 feet (M.S.L.) with limited vegetative cover in the north undeveloped area, and a high density of assorted office, warehouse and manufacturing buildings in the southern portion of the site. The drainage area contributing to the site is approximately 420 acres of dense residential and light commercial properties.

3. Flooding Problem.

Narragansett Bay, with its axis north and south and its mouth open to the Atlantic Ocean, lies in the path of hurricanes that approach the New England coast. Flooding, one of the most devastating effects of a hurricane, results from movement of the storm surge, or substantial rise in water levels, into a shoaling coast or in this case into a bay or inlet.

An important factor influencing the height of the hurricane surge is the stage of the normal tide at the time of arrival of the hurricane. The September 1938 hurricane tide reached Narragansett Bay approximately concurrrent with the predicted high tide, whereas the August 1954 hurricane tide occurred about two hours after the predicted tide. The three most damaging hurricanes since 1900 occurred in the 17 year period between 1938 and 1954. Two of these, the hurricane of September, 1938, and August, 1954 (Carol), produced flood levels of 15 to 16 feet above mean sea level at Providence (Seekonk). The hurricane of September 1944, although a severe storm, struck at a time of low tide and consequently was less damaging.

During the August 1954 storm, approximately 29 acres of the industrial complex at the project site was inundated by tidal flooding.

4. Plan of Protection

The plan shown on Plate No. 1 is designed to prevent the flooding of about 80 acres of industrial and unimproved land along the east bank of the Seekonk River against the Standard Project Hurricane which would produce a design tide level of Elevation 20.5 MSL. The local protective works would be located along the east bank of the Seekonk River, extending from high ground near Roger Williams Avenue along the westerly shore of Omega Pond and its outlet to the Seekonk River, then upstream along the Seekonk to its terminus near the Providence and Worcester Railroad trackage, just south of the Bucklin Point Sewage Treatment Facility, a distance of 6,470 feet. The project would include construction of 3,070 feet of earth dikes, 3,400 feet of concrete floodwalls, a vehicular ramp to the sewage treatment plant, a railroad stoplog structure, a pumping station and appurtenant structures. Dikes and walls would have heights above the stream bed varying from 7 to 34 feet. A vehicular ramp would be required to maintain access to the sewage treatment facility and a stoplog structure at the railroad crossing near the Omega Pond outlet. A pumping station having a discharge capacity of 65,000 gallons per minute would be provided to handle local interior drainage including industrial waste water and seepage during flood periods. Construction of the project would necessitate the taking of approximately 6.0 acres and would make available for industrial use 80 acres of flood-prone land. This project would provide protection against the Standard Project Hurricane.

5. Estimates and Annual Charges.

Estimates of Federal and non-Federal cost and annual charge for the project are shown in Tables 1 and 2. These estimates have been prepared on the basis that local interest will provide all lands, easements and rights of entry, as well as other assurances of local cooperation required under existing authorizations. Unit prices are based on average bid prices for similar work in the Rhode Island area. Annual charges are calculated at a 6-3/8 percent interest rate using a project life of 100 years.

TABLE 4-9
PRELIMINARY FIRST COSTS
SEEKONK LOCAL PROTECTION PROJECT

Description	Quantity	Unit	Unit Cost	Amount	Total
Lands & Damages					
Lands & Improvements	1	Job	L.S.	9,000	
Temp. Construction Easements	1	Job	L.S.	1,300	
Severence Damages				0	
Relocation Assistance				0	
Acquisition Cost	1	Job	L.S.	6,000	
Contingencies (20%)				3,300	
				$19,600	$19,600
Levees & Foundations					
Site Preparation	1	Job	L.S.	2,000	
Stream Control	1	Job	L.S.	1,800,000	
				1,802,000	
Levees					
Excavation	71,300	C.Y.	4.00	285,200	
Gravel Bedding	24,800	C.Y.	3.50	86,800	
Impervious Fill	232,000	C.Y.	3.90	904,800	
Pervious Fill	30,500	C.Y.	3.80	115,900	
Crushed Stone	960	C.Y.	9.50	9,120	
Riprap (100-200 lbs)	38,800	C.Y.	18.00	698,400	
Slope Protection (2" - 12" Stone)	11,400	C.Y.	12.50	142,500	
6" Perforated Pipe	3,480	L.F.	4.30	14,964	
Manholes	1	Job	L.S.	10,000	
Bulkhead Removal	1	Job	L.S.	15,000	
				2,282,684	
Common Fill	43,500	C.Y.	2.50	108,750	
Floodwalls					
Excavation	22,200	C.Y.	10.00	222,000	
Concrete (Reinf.)	19,900	C.Y.	225.00	4,477,500	
Sheet Piling	340	L.F.	12.00	4,080	
Bedding	9,500	C.Y.	3.50	33,250	

Description	Quantity	Unit	Unit Cost	Amount	Total
6" Perforated Pipe	2990	L.F.	4.30	12,857	
Manholes	1	Job	L.S.	19,500	
Pier Removal	1	Job	L.S.	30,000	
Intake Structure Removal	1	Job	L.S.	9,000	
				4,808,187	
Pumping Station					
Excavation	2660	C.Y.	5.00	13,300	
Concrete (Reinf.)	420	C.Y.	225.00	94,500	
Superstructure	1	Job	L.S.	30,000	
Pumps & Engines	1	Job	L.S.	120,000	
Sluice Gates	1	Job	L.S.	10,000	
Electrical	1	Job	L.S.	20,000	
Misc. Items	1	Job	L.S.	25,000	
				312,000	
Stop Log Structure					
Excavation	55	C.Y.	5.00	275	
Concrete (Reinf.)	30	C.Y.	225.00	6,750	
Stop Logs	7	Ea.	200.00	1,750	
Storage Bin	8	S.Y.	30.00	240	
Drainage					
Excavation	10,000	C.Y.	5.00	50,000	
RC Pipe	1	Job	L.S.	156,000	
Manholes & Covers	1	Job	L.S.	16,000	
Misc. Item	1	Job	L.S.	3,000	
Pump Station (small)	1	Job	L.S.	75,000	
				300,000	
			Subtotal	9,623,686	
Contingencies (20%)				1,924,714	
			Subtotal	11,548,400	
Engineering & Design (14%)				1,616,800	
Supervision & Administration (9.5%)				1,097,100	
				14,262,300	$14,262,300
		Total Project Cost			$14,281,900

Table 4-10
Annual Charges
Seekonk Local Protection Project
100 Year Life

Federal Investment		
Federal First Cost	$14,153,550	
Interest During Construction (6 3/8%)	902,290	
Total Federal Investment	15,055,840	
Federal Annual Charges		
Interest (6 3/8%)	926,310	
Amortization	1,900	
Total Federal Annual Charges	961,770	
Non-Federal Investment		
Lands, Easements & Right of Way	19,600	
Improvements by Local Interests	108,750	
Total Non-Federal First Costs	128,350	
Interest During Construction (6 3/8%)	8,180	
Total Non-Federal Investment	136,530	
Non-Federal Annual Charges		
Interest (6 3/8%)	8,700	
Amortization	20	
Maintenance and Operation	2,500	
Interim Replacements	1,700	
Total Non-Federal Annual Charges		$ 12,920
TOTAL ANNUAL CHARGES		$974,690

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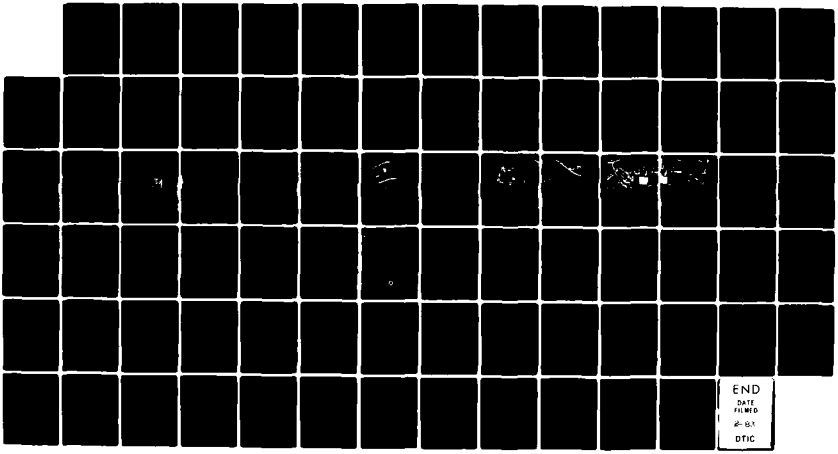

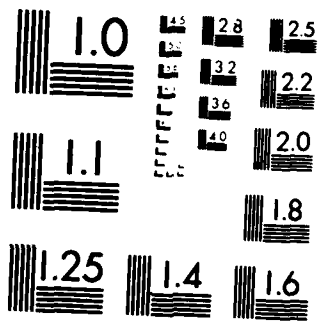

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TABLE 4-11
SUMMARY OF
PRELIMINARY ESTIMATES
OF
SIX COASTAL FLOODING PROJECTS
NARRAGANSETT BAY
(ALLINSON, INC. CONSULTANTS, JUNE 1977)

	PROTECTED AREAS	PROTECTIVE STRUCTURES	BENEFITS	COSTS	B/C RATIO
SITE 01	Warwick, East Greenwich, North Kingstown	Hurricane Barrier across entrance to Greenwich Bay, Old Hill Creek Dike crossing West Shore Dr. parallel to Church Ave.	$2,366,500	$3,224,100	0.73
SITE 02A	East Providence, Barrington, Warren, Bristol, RI; Seekonk, Swansea & Rehoboth, MA	Rumstick Neck Barrier across the mouth of Warren River with 4 dikes, Kickamut River Barrier at Bristol narrows with 2 dikes.	$7,457,700	$2,123,600	3.51
SITE 03A	East Providence, Barrington	Bullock Cove Barrier (9,890 ft) from Washington Rd. & Echo Dr. in Barrington to Terrace & Channing Aves. in East Providence with 2 dikes in Barrington.	$ 704,000	$1,472,800	0.48
SITE 02B & 03B	East Providence, Barrington, Warren Bristol, RI; Seekonk, Swansea & Rehoboth, MA	Site 02B is identical to site 02A but w/o the 4 dikes associated with Rumstick Neck Barrier. Site 03B is an extended Bullock Cove Barrier (10,870 ft) w/o the 2 dikes.	$8,870,200	$3,590,000	2.47
SITE 04	Narragansett, South Kingstown, North Kingstown	The Narrows Barrier at the mouth of the Pettaquamscutt River Little Neck Dike southwest of the barrier and west of Boston Neck Road.	$ 614,200	$ 507,900	1.21
SITE 05	North Kingstown	Wickford Harbor Barrier from Cold Spring Beach to Shore Acres.	$2,919,600	$1,453,000	2.01
SITE 06	Newport, Middletown	Easton Beach Barrier along the south and east of Easton Pond.	$ 35,400	$ 407,400	0.09
	East Providence	Walls and Dikes along the east bank of the Seekonk River from Roger Williams Ave. upstream to the Bucklin Point Sewage Treatment Facility.	$ 325,000	$ 974,690	0.33

6. **Benefits.**

Annual benefits attributable to the proposed protection works are estimated at $325,000.00, while estimated annual project costs are $974,690.00, resulting in a benefit-cost ratio of 0.33 to 1.0.

WOONASQUATUCKET RIVER BASIN

Cost Estimates

Tables 4-12 through 4-16 show preliminary cost estimates for five flood protection schemes in Providence. The first two are the costs of the channel improvements listed in the Hydrology Report for the West and Moshassuck Rivers. The other three are estimates of various methods of flood protection along the Woonasquatucket River. These involve concrete "U" channels, box conduits, stone-lined trapezoidal channels, concrete walls and a pumping station for the 100-year, 300-year and SPF levels of protection.

Table 4-12
Preliminary Cost Estimate
West River

Major Channel Improvements

Description	Quantity	Unit	Unit Cost	Total Cost
Site Preparation	1	Job	L.S.	$ 150,000
Dewatering	1	Job	L.S.	600,000
Excavation, General	143,000	C.Y.	4.60	660,000
Stone Protection	29,000	C.Y.	37.00	1,100,000
Gravel Bedding	14,000	C.Y.	7.00	98,000
Random Fill	75,000	C.Y.	3.50	260,000
Concrete (Reinf.)	16,000	C.Y.	220.00	3,500,000
Total Bridge Removal (2)	1	Job	L.S.	50,000
Total Road Removal & Replace (6)	1	Job	L.S.	51,000
Total R.R. Removal & Replace (3)	1	Job	L.S.	30,000
Weir Structure	1	Job	L.S.	65,000
				6,560,000
		Contingencies 20%		1,340,000
				$7,900,000
Note: Not Included:		E & D		1,145,000
Real Estate (easements) Utilities Relocations Temporary Access		S & A		750,000
				9,795,000

Table 4-13
Preliminary Cost Estimate
Moshassuck River

Major Channel Improvements

Description	Quantity	Unit	Unit Cost	Total Cost
Site Preparation	1	Job	L.S.	$ 130,000
Dewatering	1	Job	L.S.	830,000
Excavation, General	231,000	C.Y.	4.60	1,100,000
Stone Protection	59,000	C.Y.	37.00	2,200,000
Gravel Bedding	39,000	C.Y.	7.00	270,000
Random Fill	31,000	C.Y.	3.50	109,000
Concrete (Reinf.)	15,000	C.Y.	220.00	3,300,000
Stl. Sheet Piling	69,000	S.F.	12.00	830,000
Topsoil, seeded	5,000	S.Y.	3.00	15,000
Bascule Gate (4' x 30')	1	Job	L.S.	174,000
Bridge-Raised	1	Job	L.S.	275,000
Footbridge Removal & Replace (3)	1	Job	L.S.	29,000
Total Bridge Removal & Replace (3)	1	Job	L.S.	583,000
				$9,850,000
		Contingencies 20%		1,950,000
				$11,800,000
Note: Not Included:		E & D		1,652,000
Real Estate (easements) Utilities Relocations Temporary Access		S & A		1,062,000
				$14,514,000

TABLE 4-14

WOONASQUATUCKET RIVER
LOCAL PROTECTION PROJECT
PRELIMINARY ESTIMATE
100-YEAR EVENT (JULY 1977)

	QUANTITY		MATERIAL	
	No. Units	Unit Meas.	Per Unit	Total Cost
Removals:				
Dams	1	Job	L.S.	200,000
Bridges	1	Job	L.S.	227,000
Buildings	1	Job	L.S.	45,000
Replacements:				
Dams	1	Job	L.S.	700,000
Bridges	1	Job	L.S.	702,000
Buildings	1	Job	L.S.	43,000
Diversion of Water	1	Job	L.S.	6,000.000
Diversion Weir	1	Job	L.S.	14,250
Excavation	198,000	CY	3.25	643,500
Backfill	26,000	CY	2.75	71,500
Gravel Bedding	54,000	CY	6.50	351,000
Stone Protection	75,000	CY	20.00	1,580,000
Concrete	69,000	CY	100.00	6,900,000
Reinforcing Steel	8,365,000	LB	0.45	3,764,250
Earth Support System	130,000	SF	14.00	1,820,000
				22,981,500
Contingencies (± 25%)				5,718,500
				$28,700,000

TABLE 4-15

WOONASQUATUCKET RIVER
LOCAL PROTECTION PROJECT
PRELIMINARY ESTIMATE
300-YEAR EVENT (JULY 1977)

	QUANTITY		MATERIAL	
	No. Units	Unit Meas.	Per Unit	Total Cost
Removals:				
Dams	1	Job	L.S.	$ 200,000
Bridges	1	Job	L.S.	227,000
Buildings	1	Job	L.S.	45,000
Replacements:				
Dams	1	Job	L.S.	700,000
Bridges	1	Job	L.S.	702,000
Buildings	1	Job	L.S.	43,000
Diversion of Water	1	Job	L.S.	6,000,000
Diversion Weir	1	Job	L.S.	14,250
Excavation	348,000	CY	3.25	1,131,000
Backfill	50,000	CY	2.75	137,500
Gravel Bedding	72,000	CY	6.50	468,000
Stone Protection	103,000	CY	20.00	2,060,000
Concrete	74,000	CY	100.00	7,400,000
Reinforcing Steel	8,833,000	LB	0.45	3,974,850
Earth Support System	183,000	SF	14.00	2,562,000
				25,664,600
Contingencies (± 25%)				6,435,400
				$32,100,000

TABLE 4-16

WOONASQUATUCKET RIVER
LOCAL PROTECTION PROJECT
PRELIMINARY ESTIMATES
SPF EVENT (July 1977)

	Quantity No. Units	Unit Meas.	Material Per Units	Total Cost
Removals:				
Dams	1	Job	L.S.	200,000
Bridges	1	Job	L.S.	252,000
Buildings	1	Job	L.S.	128,000
Replacements:				
Dams	1	Job	L.S.	700,000
Bridges	1	Job	L.S.	1,518,000
Buildings	1	Job	L.S.	43,000
Diversion of Water	1	Job	L.S.	6,000,000
Diversion Weir	1	Job	L.S.	14,250
Excavation	575,000	CY	3.25	1,868,750
Backfill	30,000	CY	2.75	82,500
Gravel Bedding	58,000	CY	6.50	377,000
Stone Protection	75,000	CY	20.00	1,500,000
Concrete	145,000	CY	100.00	14,500,000
Reinforcing Steel	21,650,000	LB	0.45	9,742,500
Earth Support System	335,000	SF	14.00	4,690,000
Underpinning	750	CY	600.00	450,000
Pumping Station	1	Job	L.S	800,000
				42,866,000
Contingencies (± 25%)				10,634,000
				$53,500,000

MOSHASSUCK RIVER

PROVIDENCE RIVER BASIN

RHODE ISLAND

HYDROLOGIC ANALYSIS OF FLOODS

A

A PLANNING AID REPORT

BY

HYDROLOGIC ENGINEERING SECTION

WATER CONTROL BRANCH

ENGINEERING DIVISION

DEPARTMENT OF THE ARMY

NEW ENGLAND DIVISION, CORPS OF ENGINEERS

WALTHAM, MASSACHUSETTS

MARCH 1981

HYDROLOGIC ANALYSIS OF FLOODS
MOSHASSUCK RIVER
RHODE ISLAND

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HYDROLOGIC ANALYSIS OF FLOODS
MOSHASSUCK RIVER
RHODE ISLAND

1. PURPOSE

The purpose of this report was to present the findings of a hydrologic analysis of floods on the Moshassuck River, for use in further flood control and multiobjective planning studies. Included in the report are sections on watershed description, analysis of past floods, the standard project flood, flood frequency data and a discussion of possible structural improvements for flood control. The Soil Conservation Service of the U.S. Department of Agriculture assisted in the study by furnishing river cross section surveys.

2. WATERSHED DESCRIPTION

The Moshassuck River joins the Woonasquatucket to form the Providence River in Providence, Rhode Island. The Moshassuck has a total watershed area of 23.3 square miles, located principally in the towns of Lincoln, North Providence, Pawtucket and Providence. The watershed has an overall north to south length of about 10.4 miles. The river has one principle tributary, the West River, which joins the mainstem Moshassuck about 1.3 miles upstream from its mouth. The West and Moshassuck Rivers are more or less parallel through the length of the overall watershed. resulting in two long and narrow subwatersheds. The West River has a total drainage area of 11.1 square miles and the Moshassuck drainage area above the West River confluence is 11.2 square miles. Component areas are listed in table I and watershed map is shown on plate 1. The watershed area is rolling to hilly with rather short flow distances to the principle streams. The two streams have very flat gradients particularly in the lower reaches where gradients average between .001 and .002 ft/ft. It is largely these flat gradients that limit the conveyance capacity of the streams and aggravate recurring flood problems. Total relief in the watershed is approximately 400 feet, from about elevation 400 feet NGVD in the extreme headwaters to tidewater elevation at the Providence River.

The lower one-half of the watershed lies within the highly developed metropolitan Providence region. Much of the development along the streams in the lower watershed is the commercial-industrial type with extensive railroad and highway transportation systems. Development at the higher levels in the lower watershed is more residential and institutional.

The upper one-half of the watershed remains quite sparsely developed with a more rural character; however, the watershed is now bisected by Route 146, a new superhighway connector from Providence to Worcester, which will likely increase development pressures in the upper watershed.

A map of the Moshassuck watershed is shown on plate 1.

TABLE I

MOSHASSUCK RIVER BASIN
COMPONENT WATERSHED AREAS

Watershed	Area (sq. mi.)
Moshassuck above West River	11.2
West River	11.1
Moshassuck at USGS Gage	23.1
Moshassuck at Mouth	23.3

3. CLIMATOLOGY AND STREAMFLOW

The Moshassuck River basin has a cool semi-humid climate typical of the southern coastal areas of New England. The average annual temperature is about 50° Fahrenheit, ranging from an average summer temperature of about 70° to an average winter temperature of about 30°. Extremes in temperature range from highs of 100° to lows of -15°.

The mean annual precipitation in the area is about 40 inches and is quite uniform throughout the year but much of the precipitation in winter occurs as snow with an average annual snowfall of about 40 inches. Water content of the snowpack usually reaches a maximum in early March but rarely exceeds 2 to 3 inches water equivalent due to the moderating effect of Narragansett Bay. The area frequently experiences periods of heavy precipitation produced by local thunderstorms and intense "lows" of tropical and extratropical origin that move northeasterly up the coast.

Average annual runoff (streamflow) in the area is about 25 inches or 60 percent of average annual precipitation. The U.S. Geological Survey maintains a stream gaging station on the Moshassuck River in Providence, a short distance upstream from the mouth of the river. Drainage area of the river at the gage is 23.1 square miles, whereas, the total drainage area of the river is 23.3 square miles. The Moshassuck gage has been in continuous operation since June 1963, except for short periods of equipment malfunction.

Average, maximum and minimum monthly flows recorded at the gage are listed in table II, both in cubic feet per second (cfs) and inches of runoff. Annual peak discharges for each water year of record are listed in table III.

4. ANALYSIS OF FLOODS

The Moshassuck River basin is believed to have had a long history of flooding; howe' ", little quantitative information is available on early floodflows and depths. An analysis of some historic storm rainfalls provides an indicator of the probably magnitude of earlier floods compared with the more recent documented events. Damages from floods have increased with development in the flood plains. Some of the notable storm and flood events are discussed in the following paragraphs and summarized in table IV.

a. 11-14 February 1886. The greatest flood in the Moshassuck River basin, in the past century, likely occurred in February 1886, when a phenomenal 7.9 inches of rainfall was recorded in a 24-hour period at Pawtucket, Rhode Island. This event occurred in midwinter and was augmented by snowmelt resulting in a high antecedent moisture condition. There is little quantitative information on the resulting flood which caused extensive property damage in the Moshassuck basin with the destruction of dams, mills, bridges and buildings, and it was reported one life was lost. A recurrence, under present levels of development, would cause catastrophic losses. It is estimated that such an event would produce a flow rate in the order of 4,000 cfs at the USGS gage or a flow about 60 percent greater than that experienced and recorded in March 1968. Resulting flood levels would be an estimated 2 to 4 feet higher than those of March 1968.

b. 13 October 1895. A major rainfall, totaling 5.1 inches in 24 hours, was recorded at Pawtucket on 13 October 1895. However, it is believed only moderate flooding resulted in the Moshassuck basin, probably due to a low antecedent moisture condition, not unlike that of October 1962.

c. 16 September 1932. Another major rainfall totaling 6.7 inches in 24 hours was recorded at Pawtucket, RI in September 1932. As in October 1895, it too apparently produced only moderate flooding in the basin, probably due to both a low antecedent moisture condition and the lack of extensive development in flood plain areas.

d. 18-19 August 1955. The Providence area, including the Moshassuck basin, escaped the brunt of the record flood producing rainfalls experienced in many areas of New England in August 1955. The Providence area recorded 2.9 inches of rainfall on the 12th and 13th followed by 6 inches of rainfall on the 18th and 19th, while other areas of southern New England were experiencing 12 to 14 inches of rainfall on the 18th and 19th. As a result, the flooding on the Moshassuck was considered

TABLE II

MONTHLY RUNOFF
MOSHASSUCK RIVER AT PROVIDENCE, RI
(D.A. = 23.1 Square Miles)
16 Years of Record

Month	Mean		Maximum		Minimum	
	CFS	Inches	CFS	Inches	CFS	Inches
January	60.0	3.0	174	8.8	14.1	0.7
February	53.9	2.5	77.0	3.5	26.4	1.2
March	73.1	3.7	141	7.1	44.7	2.3
April	60.5	2.9	90.8	4.4	22.9	1.1
May	46.8	2.4	104	5.2	24.2	1.2
June	29.8	1.5	70.2	3.4	15.4	0.8
July	18.8	0.9	35.5	1.8	8.71	0.4
August	19.8	1.0	49.4	2.5	7.27	0.4
September	22.3	1.1	50.1	2.4	5.09	0.2
October	24.3	1.2	69.0	3.5	8.72	0.4
November	36.9	1.8	118	5.8	10.6	0.5
December	54.1	2.7	143	7.2	10.6	0.5
ANNUAL	41.6	24.7	62.5	37.1	20.9	12.4

TABLE III

PEAK ANNUAL DISCHARGES
MOSHASSUCK RIVER AT PROVIDENCE, RI
(D.A. = 23.1 square miles)

Date	Water Year Peak Discharge
29 Nov 1963	662
25 Feb 1965	952
23 Aug 1966	802
1 Aug 1967	1,110
18 Mar 1968	2,390
25 Mar 1969	2,000
2 Apr 1970	596
20 Aug 1971	607
10 Oct 1971	785
2 Feb 1973	980
17 Aug 1974	978
4 Mar 1975	872
30 Jul 1976	1,650
20 Oct 1976	815
26 Jan 1978	1,200
21 Jan 1979	1,480

TABLE IV

MOSHASSUCK RIVER BASIN
HISTORIC FLOODS

Date	Rainfall	Antecedent Condition	Recorded Flow (cfs)	Flooding
11-13 Feb 1886	7.9" in 24 hrs	High	-	Severe
13 Oct 1895	5.1" in 24 hrs	Low	-	Moderate
16 Sep 1932	6.7" in 24 hrs	Low	-	Moderate
19 Aug 1955	6" in 48 hrs	Medium	-	Moderately severe
5-7 Oct 1962	6.6" in 24 hrs	Low	-	Moderately severe
17-18 March 1968	5" in 48 hrs	High	2,390	Moderately Severe
March 1969	1.8" in 6 hrs	High	2,000	Moderately Severe
July 1976	4.3" in 4 hrs	Low	1,650	Moderate
24-25 Jan 1979	2.6" in 48 hrs	High	1,480	Moderate

only moderate to moderately severe, particularly when compared to the devastation experienced in other neighboring areas in southern New England.

e. 5-7 October 1962. The Providence region, including the Moshassuck basin, experienced the brunt of an intense rainstorm in October 1962. Providence recorded a 24 hour maximum of 6.6 inches on the 5th and 6th with a 3 day total of over 9 inches on the 4th through 7th. Though flooding was quite general throughout the area, only the fact that the storm occurred in the fall, under low antecedent moisture conditions, prevented more severe flood damages. Under high antecedent conditions, a similar rainfall would produce extensive flooding such as occurred in March 1968 and January 1979.

f. 17-18 March 1968. The March 1968 event on the Moshassuck was the greatest since the installation of the streamflow gaging station in 1963. The flood was produced by about 5 inches of rain on the 17th and 18th preceded by 2.2 inches on the 12th and 13th. The flooding was moderately severe due to the very high antecedent moisture conditions. Excess runoff from the 5-inch rainstorm was computed at about 3.6 inches with a resulting peak runoff rate of 2,390 cfs at the gage. An analysis of the 1968 flood development in the Moshassuck is illustrated hydrographically on plate 9.

g. 25 March 1969. The second greatest flow on the Moshassuck River since installation of the gage in 1963 occurred on 25 March 1969. The recorded 2,000 cfs flow rate resulted from about 1.8 inches of rainfall in a 6-hour period occurring at a time of high antecedent conditions with runoff augmented by snowmelt.

h. 30 July 1976. On the morning of 30 July 1976, the Moshassuck basin experienced an intense rainstorm totaling 4.3 inches in a 4-hour period, with a peak flow of 1,650 cfs at the gage. The resulting flow rate and flooding would have been much greater if the storm had occurred any other season of the year.

i. January 1979. The recent moderately severe flood event experienced in January 1979 on the Moshassuck River was not the result of a single storm but the culmination of a series of storms producing extremely high antecedent conditions in the basin. Rainfall amounts recorded at Providence during the month were 1.9 inches on the 2nd, 1.9 inches on the 7th and 8th, 1.8 inches on the 13th and 14th, 2.7 inches on the 20th and 21st and climaxed by 2.6 inches on the 24th and 25th. The recorded peak flow at the gage was 1,480 cfs and flood stages in the basin were believed generally 1 to 3 feet below those of March 1968. High watermarks were established by the Corps following this event and are shown on plates 3 through 8.

5. HYDROLOGIC MODEL

A hydrologic model of the Moshassuck River basin was developed using computer program HEC-1 entitled: "Flood Hydrograph Package". The model

was calibrated using the recorded rainfall and runoff of the March 1968 flood and a series of other lesser recorded flood events. The total watershed was divided into 21 subwatersheds as delineated on plate 2. An all basin unit graph was first developed by analysis of recorded hydrographs at the gage and Snyder's coefficients T_p, C_t and C_p were determined. A "T_p" for each subarea was then determined using the relation: $T_p = C_t(LLca)^{0.3}$, with C_t varied in proportion to the variation in the square root of the subarea slope. The computed runoff from the subareas was then combined and routed through storages and river reaches to the site of the gage. Final adjustment in the unit graph coefficients was then made as necessary to produce a reasonably good reproudction of the recorded 1968 flood hydrograph.

A listing of the computer input for the March 1968 flood simulation, showing adopted unit graph coefficients, drainage areas, routing coefficients and other required information is attached as inclosure 1. Summary printouts of peak discharges for the March 1968, 100-year synthetic and standard project floods are attached as inclosures 2, 3 and 4. A summary of discharges is shown in table V.

6. 100-YEAR SYNTHETIC FLOOD

A 100-year synthetic flood was computed using the 100-year storm rainfall in the adopted hydrologic model. Rainfall amounts were determined from U.S. Weather Bureau Technical Paper No. 40. One hundred year rainfall amounts for various durations were determined and used to develop a 100-year "balanced" storm. The maximum 2-hour rainfall was 3.2 inches, the 12-hour was 6.4 and the 24-hour 7.0 inches. Rainfall losses used in the development of the 100-year synthetic flood are as follows: Initial loss (STRTL) = 0.5 inch, uniform rainfall loss (CNSTL) = 0.07 inch, maximum allowable loss (ALSMX) = 0.10 inch, and the proportion of drainage basin assumed impervious (RTIMP) = 0.15. This resulted in a total 24-hour loss of 1.5 inches, a maximum 2-hour rainfall excess of 2.9 inches, and a 12-hour excess of 5.3 inches. The resulting computed peak flow at the Moshassuck gage was 4,200 cfs. The peak flow of the river upstream of the West River was 1,940 cfs and the peak flow of the West River was 2,720 cfs. Development of the 100-year synthetic flood is graphically illustrated on plate 9.

7. STANDARD PROJECT FLOOD

A standard project flood was developed for the Moshassuck basin using the standard project index rainfall in the adopted hydrologic model. The 24-hour index rainfall for the 23-square mile watershed was 12.6 inches taken from Engineering Manual 1110-2-1141 entitled: "Standard Project Flood Determinations". The maximum 2-hour rainfall was 4.7 inches, the 12-hour was 8.0 and the 24-hour was 12.6 inches. Rainfall losses used in the development of the standard project flood are as follows: initial loss (STRTL) = 0.5 inch, uniform rainfall loss (CNSTL) = 0.07 inch, maximum allowable loss (ALSMX) = 0.10 inch and

TABLE V

FLOOD COMPARISONS
MOSHASSUCK RIVER
AT PROVIDENCE, RHODE ISLAND
(D.A. = 23.1 square miles)

Flood	Peak Flow (cfs)	Rainfall Inches	Rainfall Hours
March 1968	2,390	5.0	48
March 1969	2,000	1.8	6
July 1976	1,650	4.3	4
January 1979	1,480	2.6	48
10-yr frequency	1,900	4.1	12
100-yr frequency	4,200	6.0	12
Standard Project	8,300	12.6	24

the proportion of drainage basin that is impervious (RTIMP) = 0.15. The resulting computed peak flow of the Moshassuck River at the USGS gage was 8,300 cfs with a peak flow upstream of the West River of 3,950 cfs. Peak flow of the West River was 5,250 cfs.

8. FLOOD FREQUENCIES

The Moshassuck River USGS gage at Providence, measures flows from 23.1 square miles of area and has a continuous record from 1963 to present. Discharge frequencies were developed by analysis of peak flow records at the gage. The mean, standard deviation and adopted skew coefficient for the Moshassuck River at the gage was 3.0114, 0.1786 and 0.7, respectively. The developed discharge frequency curves are shown on plate 10.

The U.S. Geological Survey's computer system "WATSTORE" was utilized to develop the statistical data. This system analyzed peak flow data using the Log-Pearson type III statistical distribution as described in "Statistical Methods in Hydrology" by L. Beard, dated June 1962, and in U.S. Water Resources Council Bulletin No. 17A "Guidelines for Determining Flood Flow Frequency", dated June 1977.

Discharges of the four record floods at Providence and the computed 10-year and 100-year frequency flows are listed in table V.

9. FLOOD PROFILES

Flood profiles for the Moshassuck and its tributary, the West River, are shown on plates 3 through 8. Profiles were computed by standard backwater procedures using a minimum of river cross sections and the computer program HEC-2, developed by the Hydrologic Engineering Center in Davis, California. The computer backwater model was calibrated against the January 1979 flood elevations. Backwater computations were made for various floods using a Mannings "n" of .015 to .02 for concrete channels. .025-0.030 for riprapped channels, .04 to .05 for normal unimproved channels and 0.06 for overbank. Assumed contraction and expansion loss coefficient were 0.3 and 0.5, respectively for unimproved channels and 0.2 and 0.3 for improved channels with gradual transitions.

10. FLOOD CONTROL PLANS

a. General. Flooding on the Moshassuck River, and its tributary the West River, is due in large part to the extremely flat gradients of the river, averaging between .001 and .002, and the shallow nature of the channels which limit the safe conveyance capacity of the rivers. The resulting flood damage potential is also ever increasing due to past and continuing development in the flood plains. Any plan for flood control must include nonstructural plans involving flood plain zoning, flood insurance, flood proofing of existing structures, relocation of high

damage materials and utilities within existing structures, along with a continuing program of channel cleaning and maintenance.

Due to the character of the channels and watershed, no simple or localized structural improvements were found that would provide effective flood control and all structural plans were major in scope, disruptive, and costly. Also, no suitable or practical sites were available in the basin for construction of flood control reservoirs. Construction of a series of dikes and walls along the river channels was not considered practical due to the scarcity of space, numerous railroad and highway crossings and most importantly, the extensive provisions that would be required for interior drainage. Two major structural plans of improvement, developed for further consideration in cost and plan formulation studies, consisted of a major channel improvement plan and a major tunnel bypass plan.

b. Channel Improvement Plan. The lowest flood prone areas (those most susceptible to flooding) are the West River in the vicinity of Charles Street (station 24+00), the shopping center (station 65+00) and the industrial complex near Branch Avenue (station 75+00). Similarly, flood prone properties on the mainstream Moshassuck River are along the right bank upstream of Randall Street (station 40+00), the left bank upstream of Industrial Street (station 60+00) and the industrial complex at Mineral Spring Avenue (station 185+00). Due to the flat gradients of the streams, it was determined that channel improvements would have to be made for a considerable distance downstream of the flood prone properties in order to realize significant flood stage reductions. For this reason, major channel improvements would commence at about station 28+00 on the Moshassuck River and continue up to the mouth of the West River (station 66+00) and then up the West River to station 80+00. Improvements would not be made on the Moshassuck between stations 66+00, 118+00 except for the modification of a footbridge at station 98+00. Improvements on the Moshassuck would commence again upstream of Smithfield Avenue (station 118+00) and continue upstream to Mineral Spring Avenue (station 190+00).

Improvements would consist mainly of lowering the channel invert an average of about 4 feet, thereby providing safe channel capacity, at the flood prone areas, equal to approximately the computed 100-year frequency discharge.

A summary of improvements on the Moshassuck and West Rivers is listed in table VI. A modified profile and index stage-discharge curves are shown on plates 3 through 8 and plate 11, respectively.

c. Diversion Tunnel Plan. An alternate to major channel improvements would be the construction of a large diversion tunnel which would intercept and direct floodflows from the West and Moshassuck Rivers east

to the Seekonk River. Such a tunnel would have an inlet on the West River at about station 82+00 and run northeasterly to a junction with the Moshassuck River at about station 195+00. From the Moshassuck, the tunnel would continue southeasterly, outletting to the tidal Seekonk River. Distance from the West River to the Moshassuck would be about 8,500 feet and from the Moshassuck to Seekonk about 7,000, for an overall length of approximately 15,500 feet.

An 18-foot diameter tunnel would have capacity to divert 2,000 cfs from the West River and 1,500 cfs from the Moshassuck for a total of 3,300 cfs to the Seekonk. This capacity would meet requirements for the computed 100-year flood event. Hydraulic head loss between the West and Moshassuck Rivers would be about 9 feet and between the Moshassuck and Seekonk, about 21 feet based on a Manning "n" tunnel roughness coefficient of 0.015.

It was further determined that a 24-foot diameter tunnel would be required to divert the standard project floodflows with comparable hydraulic head losses.

TABLE VI

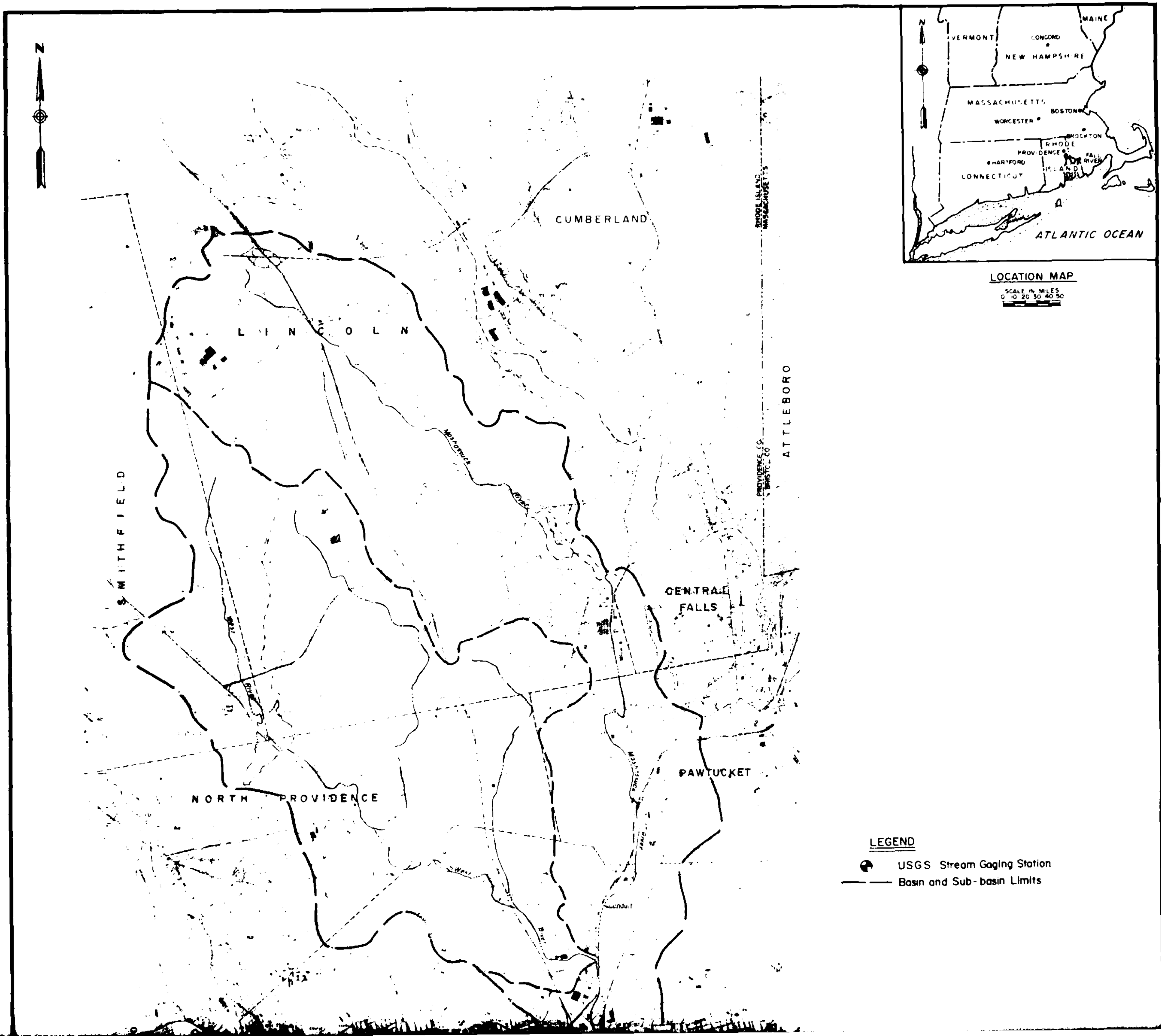
CHANNEL IMPROVEMENT SUMMARY

MOSHASSUCK RIVER

Station	Improvement	Channel Invert (ft NGVD)	100 yr Q (cfs)	100 yr El (ft NGVD)
26+00	Raise Mill St. Low Chord to 13 ft NGVD minimum	-	-	-
28+40	Install 4 foot high, 30 ft long bascule gage	6	4,200	14.4
28+40 to 39+00	Provide 30 ft wide concrete rectangular channel or modified 35 ft wide channel with 13 ft bottom 3:1 side slopes to 4 foot depth then vertical sides	6 to 8.2	4,200	17.9
39+00 to 54+70	Trapezoidal channel with 20 foot bottom and 2:1 riprapped side slopes	8.2 to 11.4	4,200	23.4
54+70 to 66+00	Provide either 30 ft wide concrete rectangular channel or the 20 foot trapezoidal channel with hydrologically efficient transitions	11.4 to 13.6	4,200	27.4
71+20	d/s face twin conduit	17.0	4,200	27.7
97+50	Elevate footbridge	21.5	2,000	28.8
115+20 to 131+90	Trapezoidal channel with 20 foot bottom and 2:1 side slopes	23.5 to 24.9	2,000	36.8 to 37.5
131+90	Replace Greenville Avenue bridge with 20 foot clear span with efficient transitions	24.9	2,000	37.5
131+90 to 174+80	Trapezoidal channel with 20 foot bottom and 2:1 side slopes	24.9 to 29.2	2,000	41.0
174+80	Replace Grotto Avenue with 20 ft clear span with efficient transitions	29.2	2,000	41.0
174+80 to 194+30	Trapezoidal channel with 20 foot bottom and 2:1 side slopes. Replace bridges with 20 foot clear span	31.0	2,000	43.3
202+40	Existing invert elevation	39.0	2,000	46.7

WEST RIVER

Station	Improvement	Channel Invert (ft NGVD)	100 yr Q (cfs)	100 yr El (ft NGVD)
0+0	Lower invert of existing twin conduits 3 feet	14	2,500	27.4
2+40 to 8+00	Trapezoidal channel with 10 foot bottom and 2:1 riprapped side slopes	14 to 15.2	2,500	28.5
8+00 to 25+30	Provide 20 foot wide concrete rectangular channel or twin 12 foot wide by 10 foot high conduits	15.2 to 18.4	2,500	33.0
25+30 to 51+20	Trapezoidal channel with 10 foot bottom and 2:1 riprapped side slopes	18.4 to 23.4	2,500	33.8
51+20	Lower invert about 6 feet under Hawkins Street with trapezoidal section	23.4	2,500	33.8
51+20 to 58+20	Trapezoidal channel with 10 foot bottom and 2:1 riprapped side slopes	23.4 to 25.8	2,500	34.8
58+20 to 60+00	Lower invert of existing twin conduits 3.8 feet	26.2	2,500	37.7
60+20 to 69+00	Trapezoidal channel with 10 foot bottom and 2:1 riprapped side slopes	26.2 to 28.0	2,500	38.5
69+00 to 80+00	Twin 12 foot wide by 10 foot high conduits	28.0 to 30	2,500	38.9
80+00 to 81+00	Inlet transition from twin 12 foot conduits to 65 ft wide rectangular section at entrance with sill at elevation 40 foot NGVD	30 to 40	2,500	45.3



N
CUMBERLAND
LINCOLN
SMITHFIELD
CENTRAL FALLS
PAWTUCKET
NORTH PROVIDENCE
ATTLEBORO
RHODE ISLAND
MASSACHUSETTS
PROVIDENCE CO.
BRISTOL CO.
Moshassuck River
West River
Conduit
VERMONT
NEW HAMPSHIRE
MAINE
CONCORD
MASSACHUSETTS
BOSTON
WORCESTER
BROCKTON
RHODE ISLAND
PROVIDENCE
FALL RIVER
HARTFORD
CONNECTICUT
ATLANTIC OCEAN
LOCATION MAP
SCALE IN MILES
0 10 20 30 40 50
LEGEND
USGS Stream Gaging Station
Basin and Sub-basin Limits

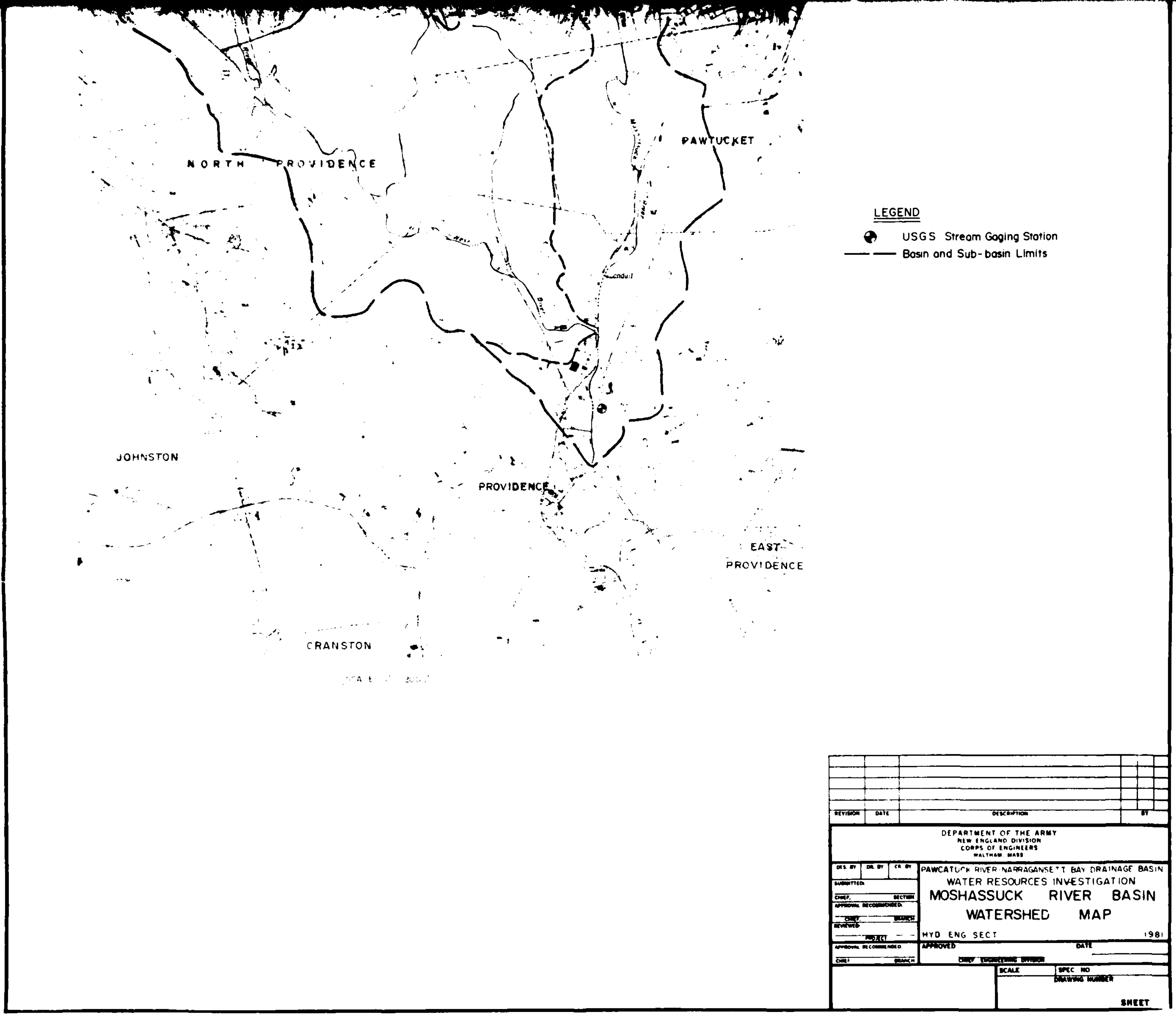
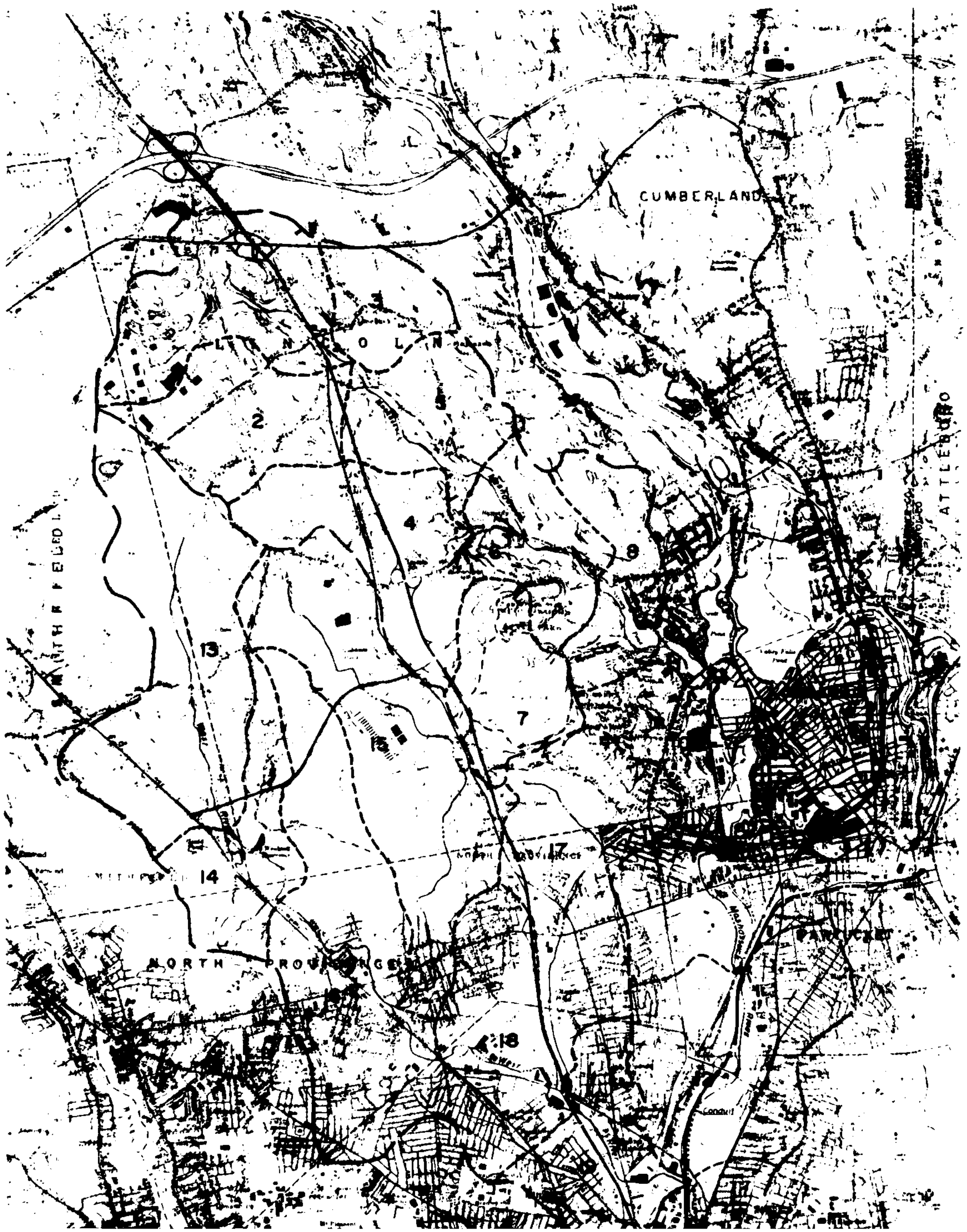

NORTH PROVIDENCE
PAWTUCKET
JOHNSTON
PROVIDENCE
EAST PROVIDENCE
CRANSTON
LEGEND
USGS Stream Gaging Station
Basin and Sub-basin Limits
REVISION
DATE
DESCRIPTION
BY
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS
PAWCATUCK RIVER-NARRAGANSETT BAY DRAINAGE BASIN
WATER RESOURCES INVESTIGATION
MOSHASSUCK RIVER BASIN
WATERSHED MAP
HYD ENG SECT
1981
APPROVED
DATE
SCALE
SPEC NO
DRAWING NUMBER
SHEET

PLATE I

2



LOCATION MAP

SCALE IN MILES
0 10 20 30 40 50

DRAINAGE AREA IN SQUARE MILES				
RIVER SUB-BASIN		INCREMENTAL D A		TOTAL D A
MOSHASSUCK RIVER	WEST RIVER	MOSHASSUCK	WEST	
1		1 3		
2		1 0		
3		0 5		
4		1 2		
5		0 9		
6		0 9		
7		0 8		
8		0 7		
9		0 1		
10		1 0		
11		1 1		
12		1 7		11 2
	13		2 2	
	14		0 9	
	15		2 2	
	16		2 2	
	17		1 6	
	18		1 2	
	19		0 8	11 1
20		0 8		23 1
21		0 2		23 3

LEGEND

USGS Stream Gaging Station

River Basin Limits

Sub-basin Limits

SCALE 1" = 2000'

LEGEND

USGS Stream Gaging Station

River Basin Limits

Sub-basin Limits

REVISION	DATE	DESCRIPTION	BY

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

PAWCATUCK RIVER – NARRAGANSETT BAY DRAINAGE BASIN
WATER RESOURCES INVESTIGATION

MOSHASSUCK RIVER BASIN
HYDROLOGIC SUB-BASIN MAP

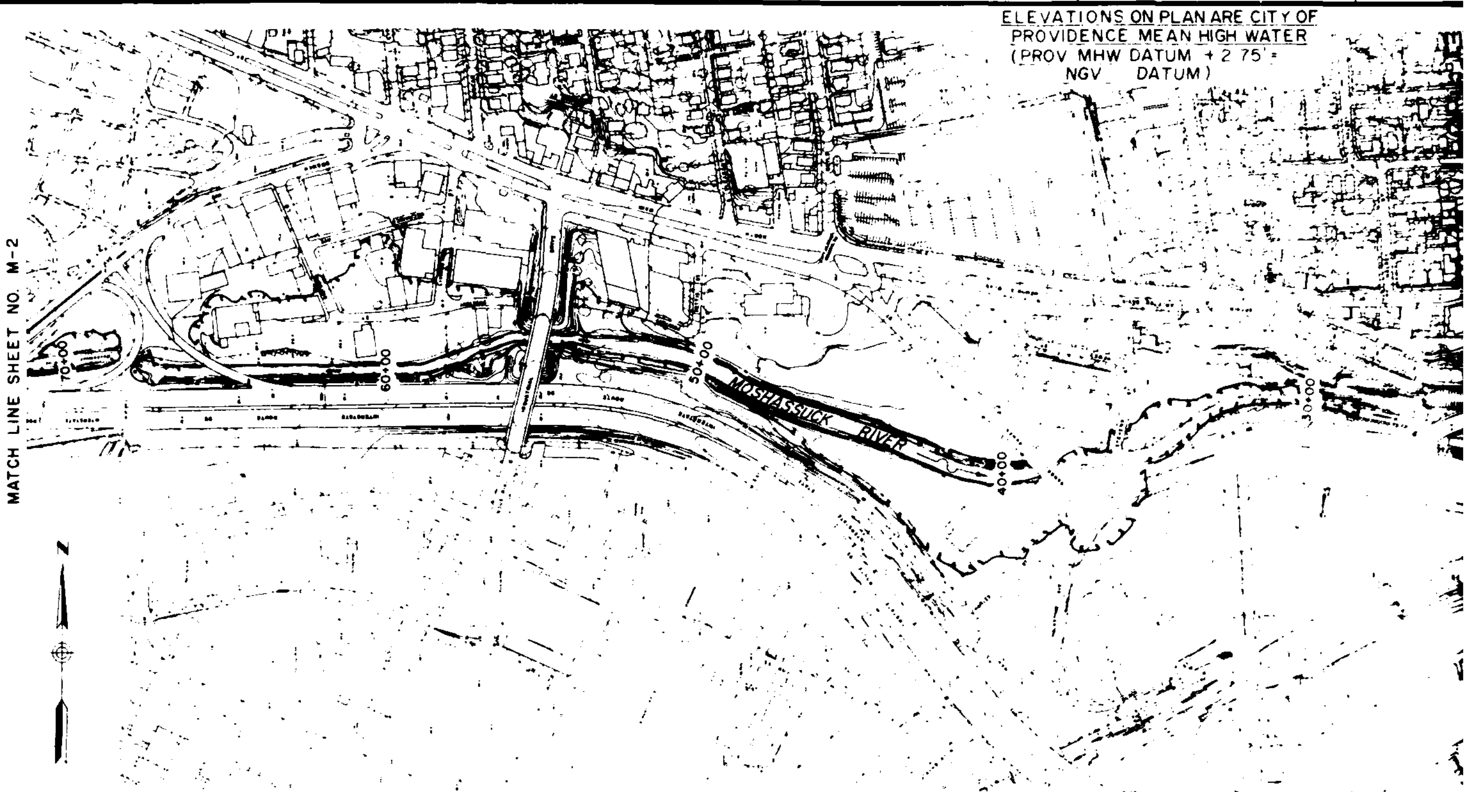
HYDRO. ENG. SECT. 1981

DES. BY | DR. BY | CK. BY
SUBMITTED:
CHIEF, SECTION
APPROVAL RECOMMENDED:
CHIEF, BRANCH
REVIEWED:
PROJECT
APPROVAL RECOMMENDED:
CHIEF, BRANCH
APPROVED | DATE
CHIEF, ENGINEERING DIVISION
SCALE | SPEC. NO.
DRAWING NUMBER
SHEET

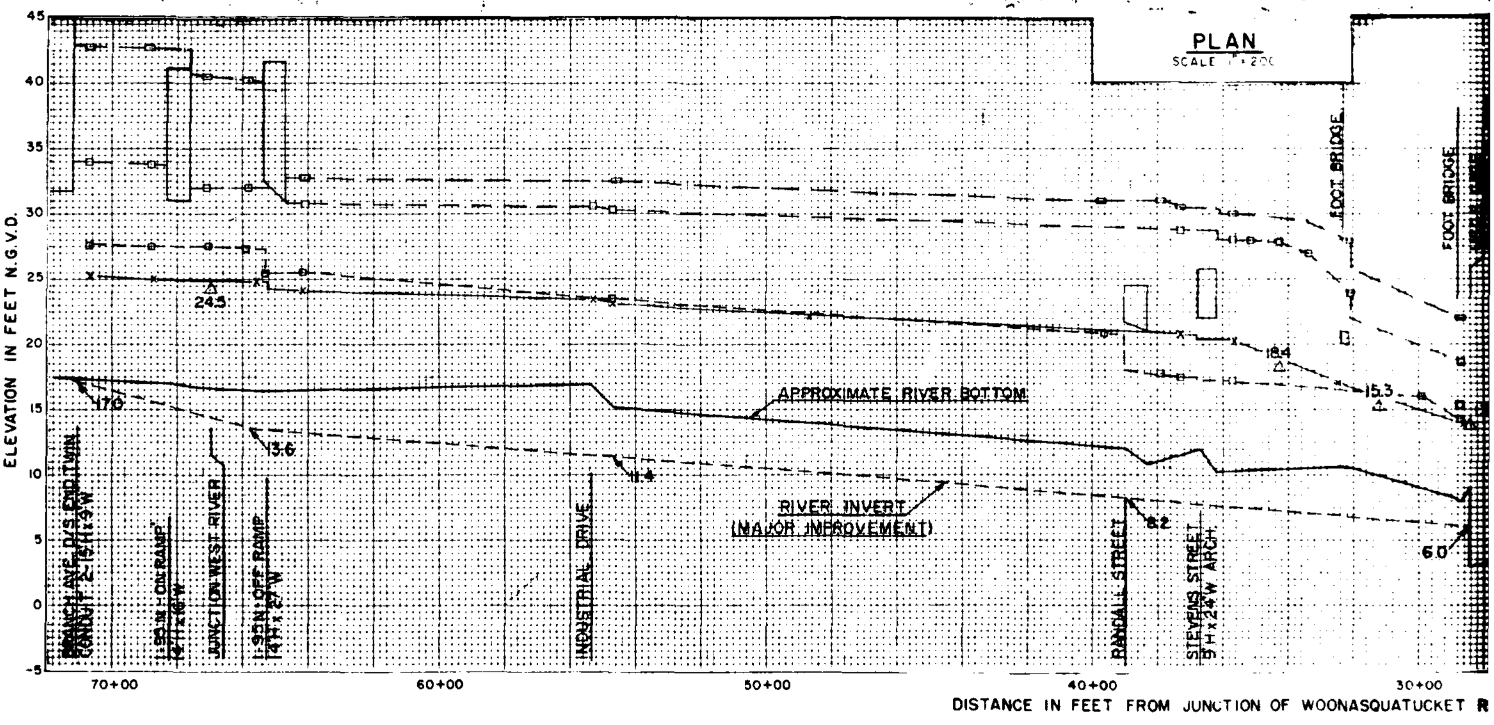
2

PLATE 2

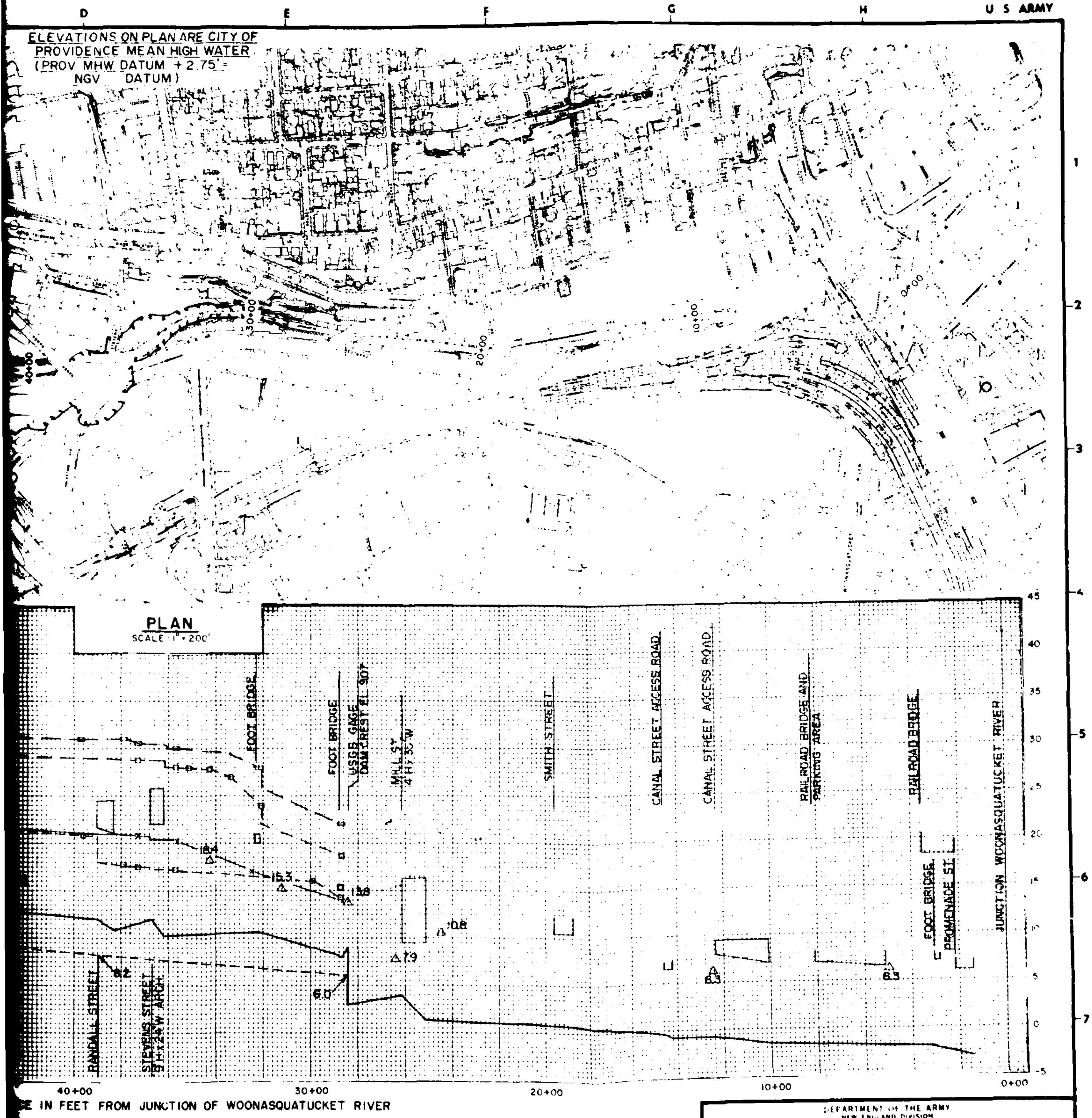
CORPS OF ENGINEERS



PLAN
SCALE 1" = 200'



PROFILE
SCALE HOR 1" = 200' VERT 1" = 5'



DISTANCE IN FEET FROM JUNCTION OF WOONASQUATUCKET RIVER

PROFILE

SCALE HOR 1" = 200'
VERT 1" = 5'

NOTES

1. ELEVATIONS ON PLAN ARE CITY OF PROVIDENCE MEAN HIGH WATER (PROV M.H.W. DATUM + 2.75' = N.G.V.D. DATUM)
2. △ HIGH WATER ELEVATION JAN. 1979
   - JAN 1979 FLOOD COMPUTED
   - STANDARD PROJECT FLOOD
   - 100 YEAR FREQUENCY FLOOD
   - 100 YEAR FREQUENCY FLOOD MAJOR IMPROVEMENTS
   - APPROXIMATE 100 YR. FLOOD PLAIN

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS

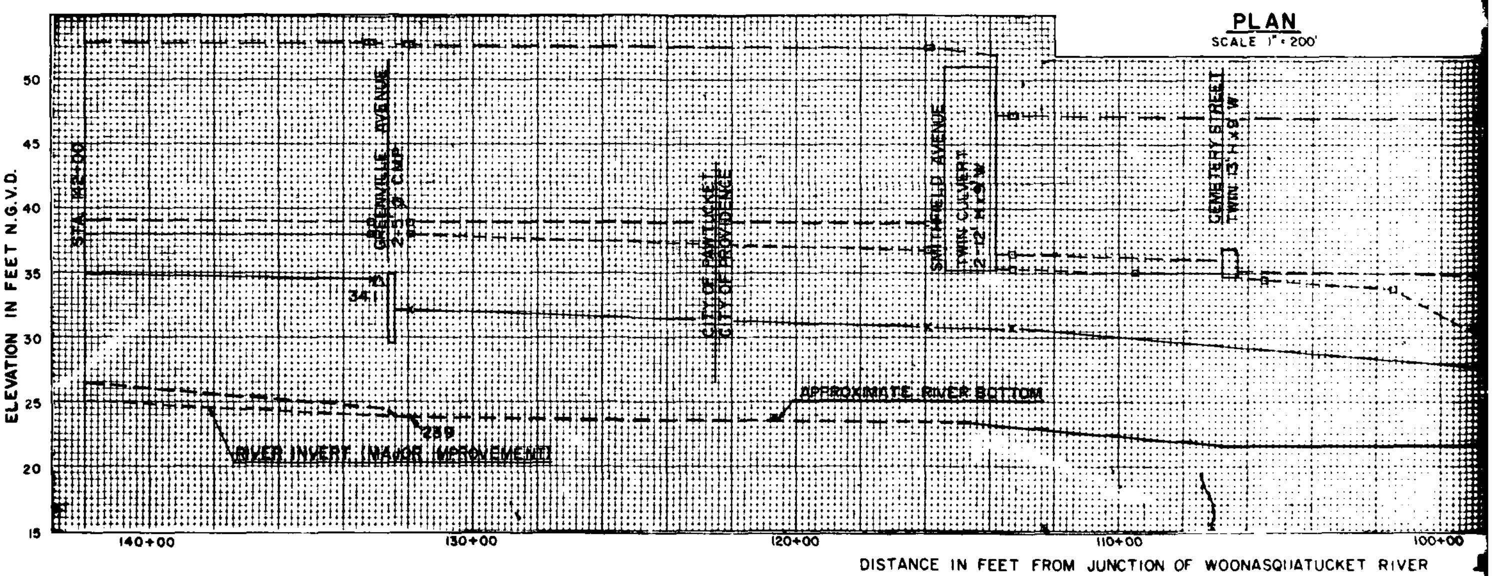
PAWCATUCK RIVER - NARRAGANSETT BAY DRAINAGE BASIN
WATER RESOURCES INVESTIGATION
MOSHASSUCK RIVER
PLAN & PROFILE NO M-1
HYDRO ENG SECT 1980

DES. BY / DR. BY / CK. BY	APPROVED / DATE
SUBMITTED	CHIEF, ENGINEERING DIVISION
CHIEF, SECTION	SCALE
APPROVAL RECOMMENDED	SPEC. NO.
CHIEF, TECH. ENG. BRANCH	DRAWING NUMBER
REVIEWED / PROJECT ENGINEER	SHEET
APPROVAL RECOMMENDED / CHIEF, BRANCH	

PLATE 3

2

PLAN
SCALE 1" = 200'

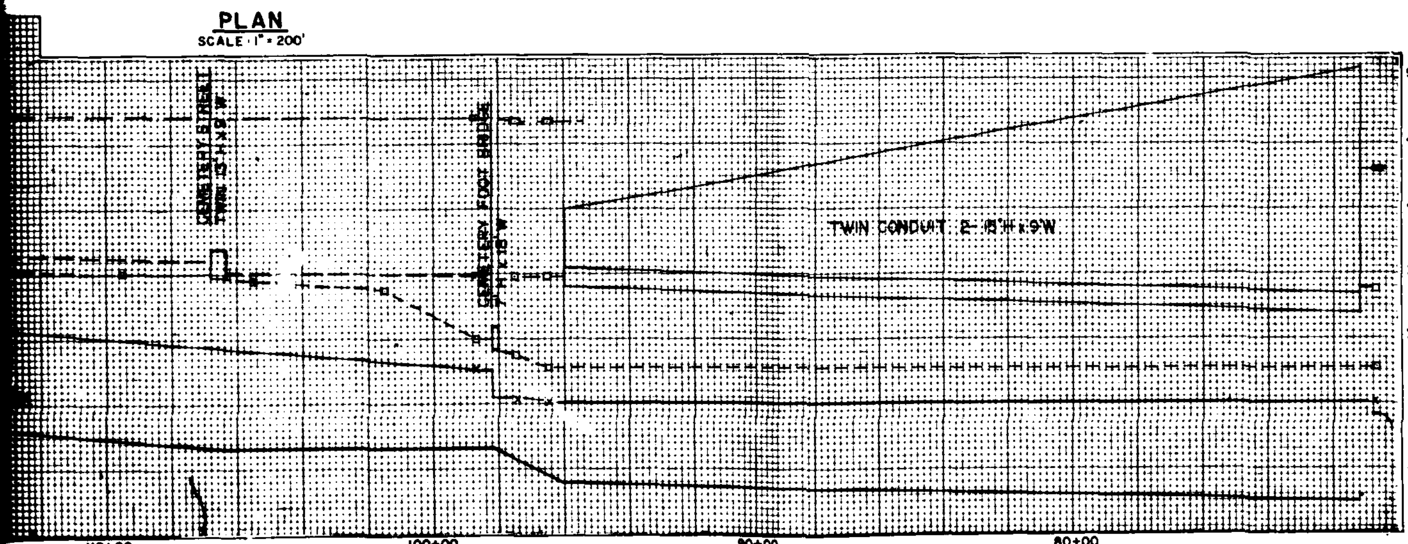


PROFILE
SCALE HOR 1" = 200'
VERT 1" = 5'

U. S. ARMY

PLAN

SCALE 1" = 200'



FROM JUNCTION OF WOONASQUATUCKET RIVER

PROFILE

SCALE: HOR 1" = 200'
VERT 1" = 5'

NOTES:

1. ELEVATIONS ON PLAN TO RIVER STATION 125+00 ARE CITY OF PROVIDENCE MEAN HIGH WATER, BEYOND STA 125+00 ELEVATION ARE NATIONAL GEODETIC VERTICAL DATUM (PROV. M.H.W. DATUM +2.75' = NGV DATUM)
2. △ HIGH WATER ELEVATION JAN 1979

—x— JAN 1979 FLOOD COMPUTED

-·◇ STANDARD PROJECT FLOOD

—□— 100 YEAR FREQUENCY FLOOD

-○- 100 YEAR FREQUENCY FLOOD (MAJOR IMPROVEMENT)

APPROXIMATE 100-YR. FLOOD PLAIN

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

PAWCATUCK RIVER - NARRAGANSETT BAY DRAINAGE BASIN

WATER RESOURCES INVESTIGATION

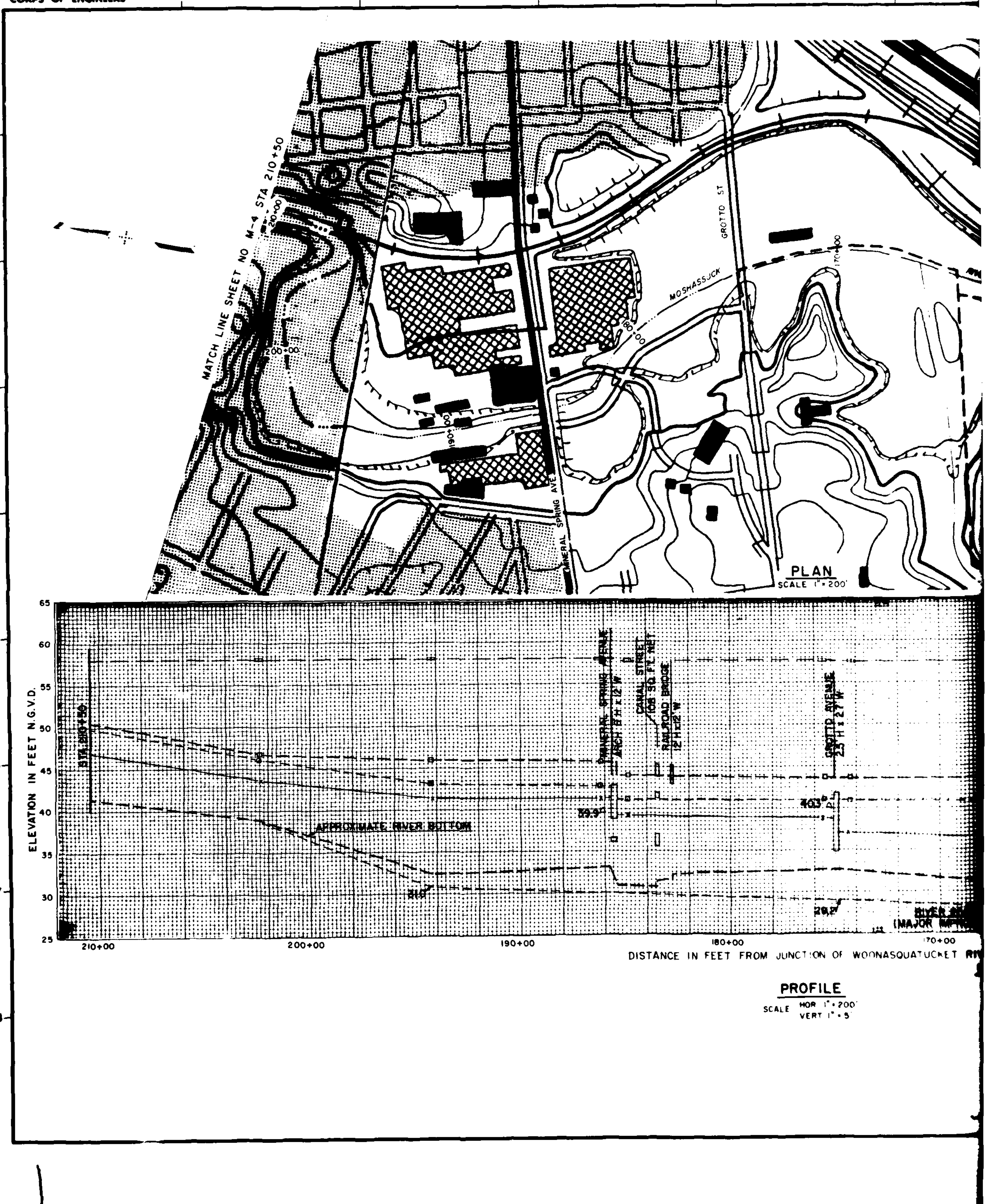
MOSHASSUCK RIVER
PLAN & PROFILE NO M-2

HYDRO ENG SECT 1980

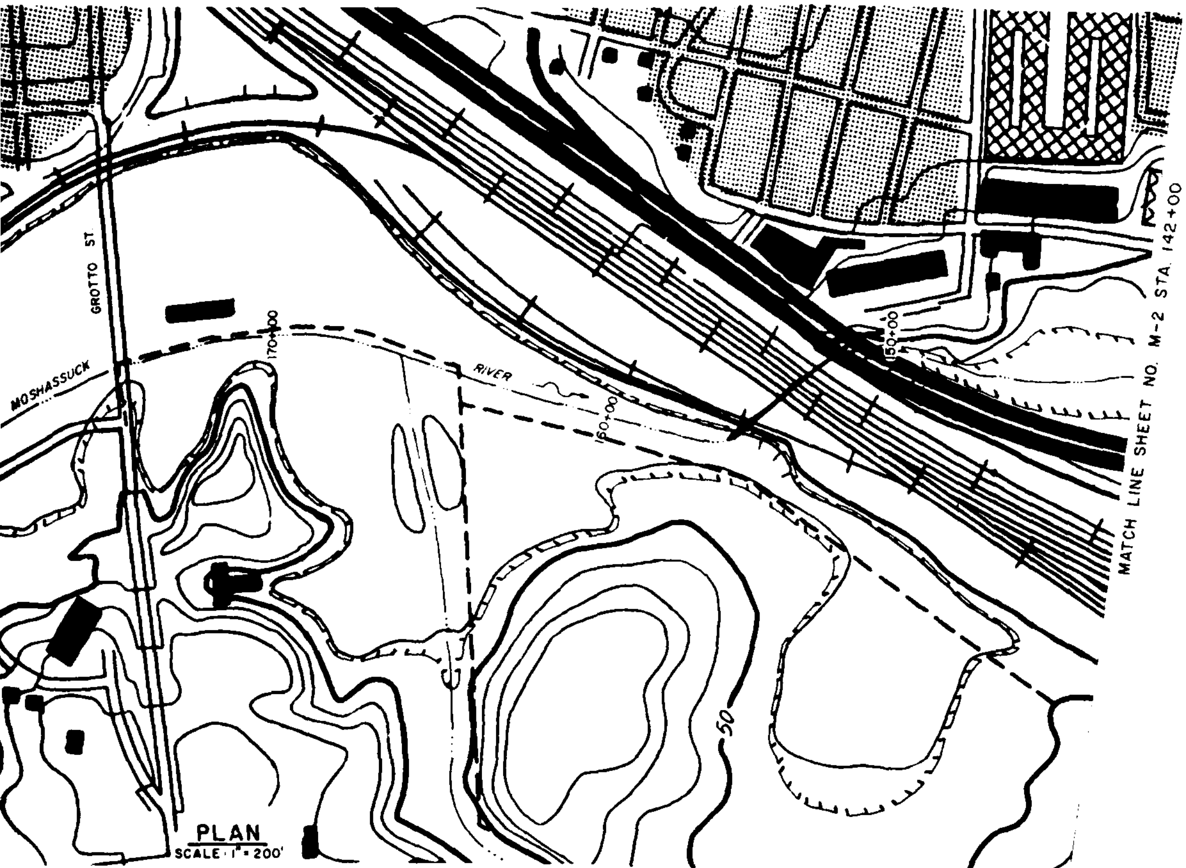
PLATE 4

2

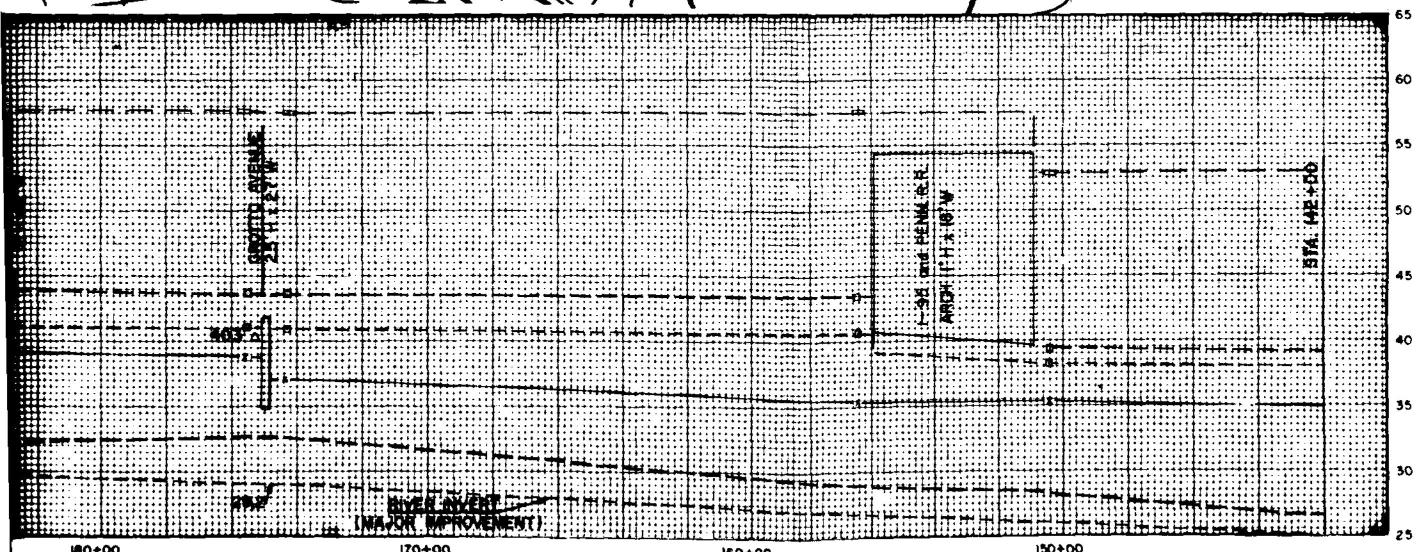
CORPS OF ENGINEERS



U. S. ARMY



PLAN
SCALE 1" = 200'



IN FEET FROM JUNCTION OF WOONASQUATUCKET RIVER

PROFILE

SCALE: HOR 1" = 200'
VERT 1" = 5'

NOTES:

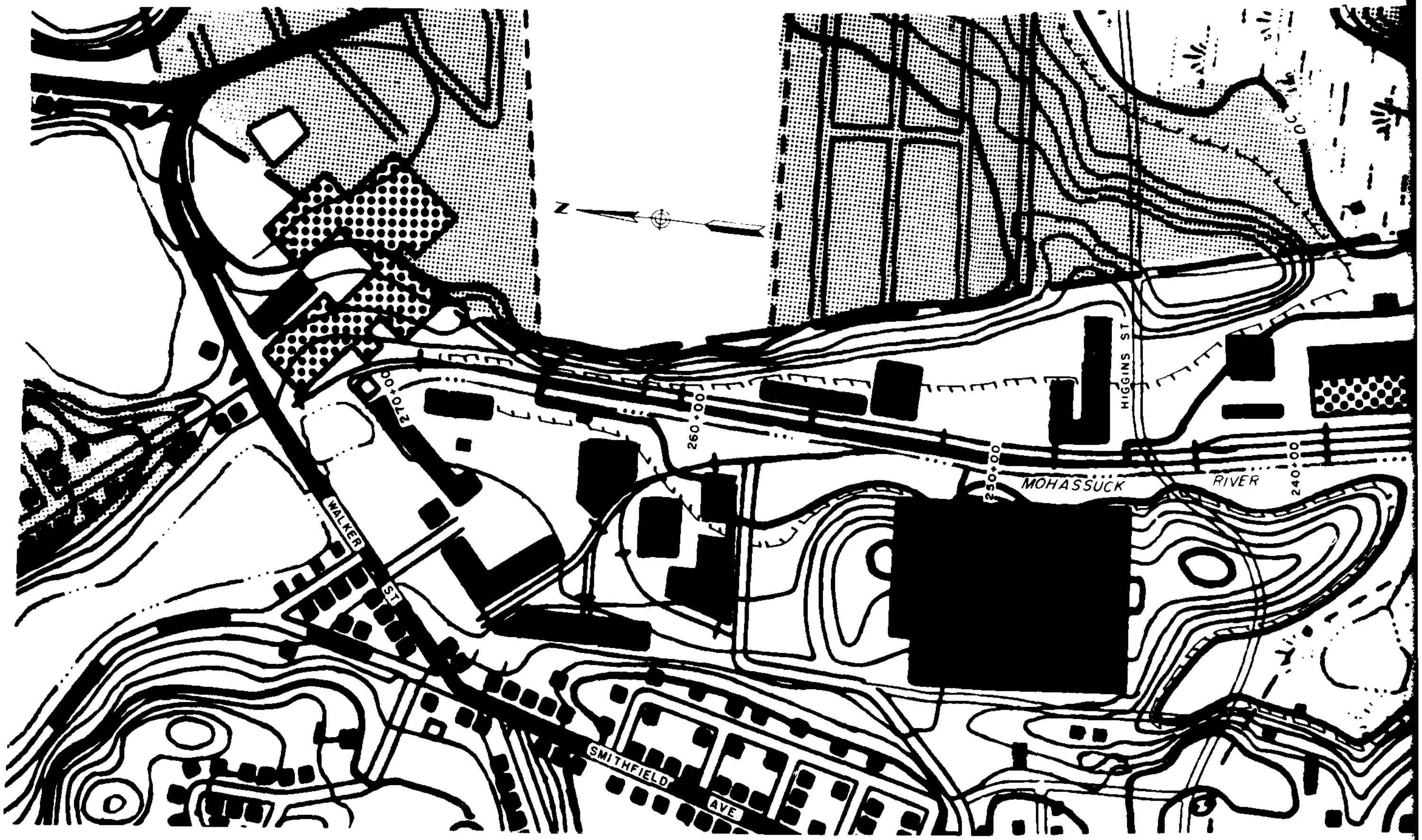
1. ADJUSTMENT TO STATIONING ON MAP WERE REQUIRED BECAUSE OF DISTORTION IN THE PHOTO ENLARGEMENT PROCESS.
2. PROFILE STATIONING FROM U.S.G.S. TOPOGRAPHIC MAP. STRUCTURE ELEVATIONS FROM FIELD SURVEY.
3. △ HIGH WATER ELEVATION JAN 1979

—x— JAN 1979 FLOOD COMPUTED
—□— STANDARD PROJECT FLOOD
—○— 100 YEAR FREQUENCY FLOOD
—+— 100 YEAR FREQUENCY FLOOD (MAJOR IMPROVEMENT)
APPROXIMATE 100 YR FLOOD PLAIN

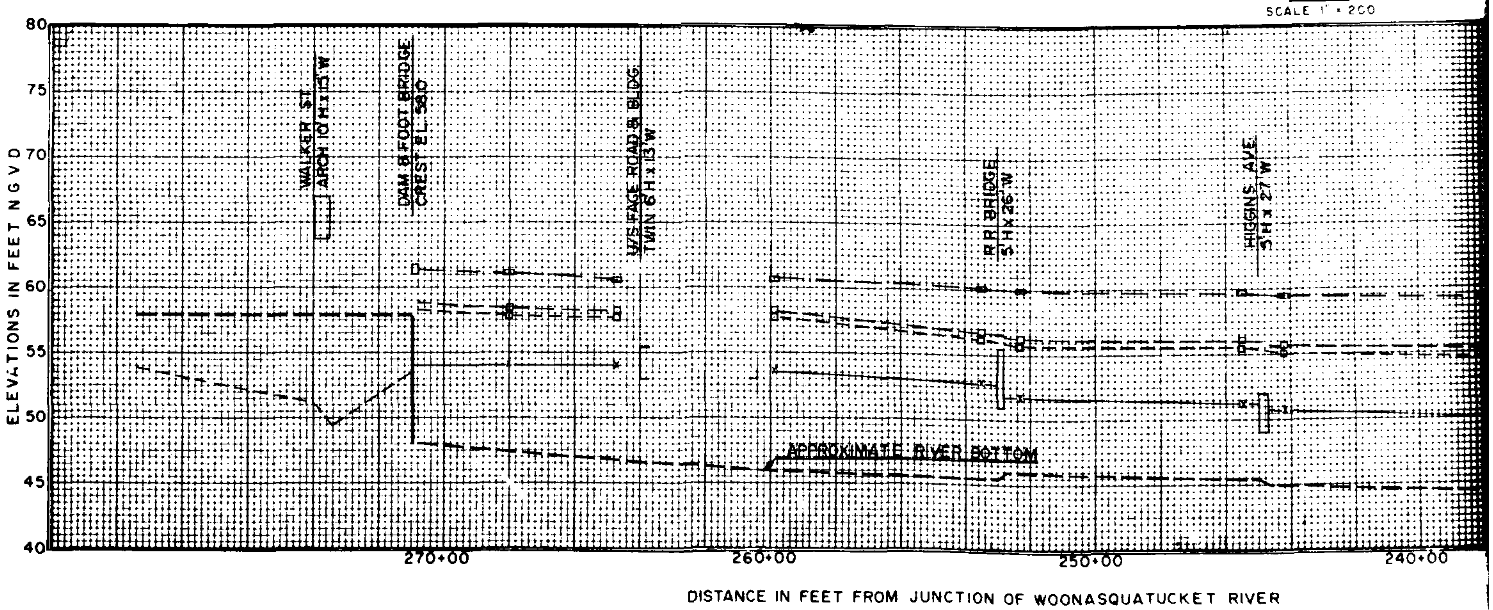
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

PAWCATUCK RIVER-NARRAGANSETT BAY DRAINAGE BASIN
WATER RESOURCES INVESTIGATION
MOSHASSUCK RIVER
PLAN & PROFILE NO. M-3
HYDRO ENG SECT 1980
APPROVED DATE
SCALE AS SHOWN SPEC. NO.
DRAWING NUMBER
SHEET

PLATE 5

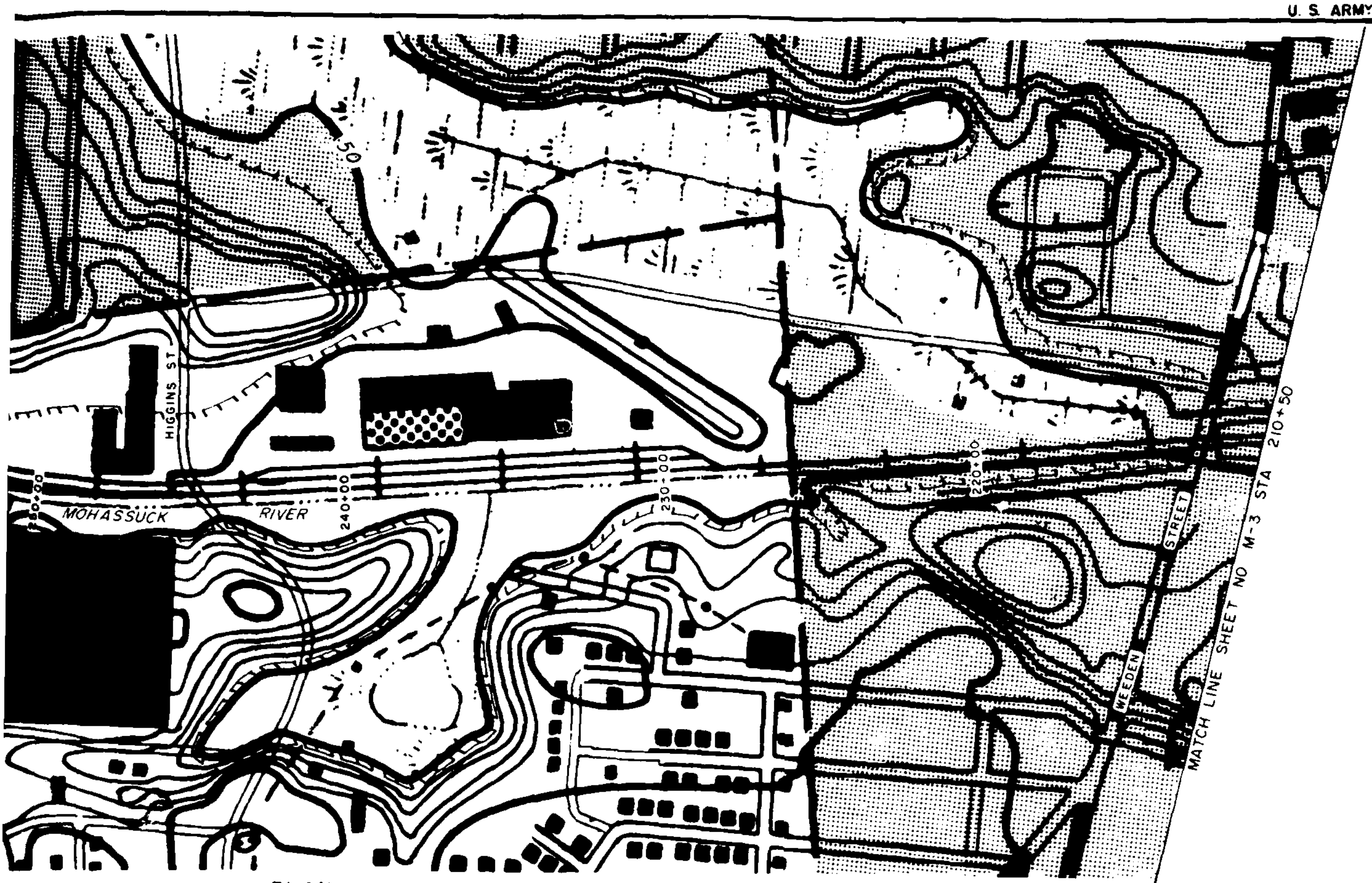


PLAN
SCALE 1" = 200

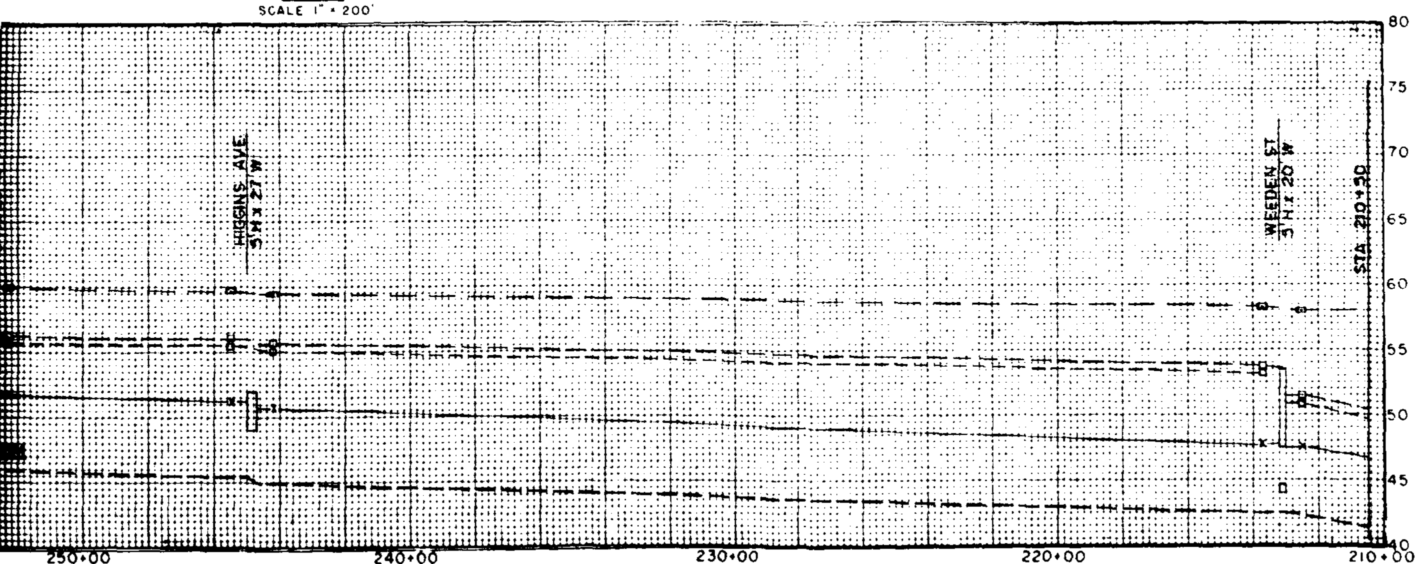


PROFILE
SCALE HOR 1" = 200
VER 1" = 5

U. S. ARMY



PLAN
SCALE 1" = 200'



F WOONASQUATUCKET RIVER

NOTES

1. MAP STATIONS ADJUSTED BECAUSE OF PHOTO-ENLARGEMENT DISTORTIONS
2. PROFILE STATIONS FROM U S G S TOPO MAP STRUCTURE ELEVATIONS FROM FIELD SURVEYS

—X— JAN 1979 FLOOD COMPUTED
—○— STANDARD PROJECT FLOOD
—□— 100 YEAR FREQUENCY FLOOD
—+— 100 YEAR FREQUENCY FLOOD (MAJOR IMPROVEMENT)
APPROXIMATE 100 YR FLOOD PLAIN

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS

DES BY	DR BY JBM	CK BY	PAWCATUCK RIVER - NARRAGANSETT BAY DRAINAGE BASIN
SUBMITTED:			WATER RESOURCES INVESTIGATION
CHIEF SECTION			
APPROVAL RECOMMENDED:			MOSHASSUCK RIVER PLAN & PROFILE NO. M-4
CHIEF BRANCH			
REVIEWED			HYDRO ENG SECT 1980
APPROVAL RECOMMENDED			APPROVED DATE
CHIEF			CHIEF ENGINEERING DIVISION
			SCALE SPEC NO DRAWING NUMBER
			SHEET

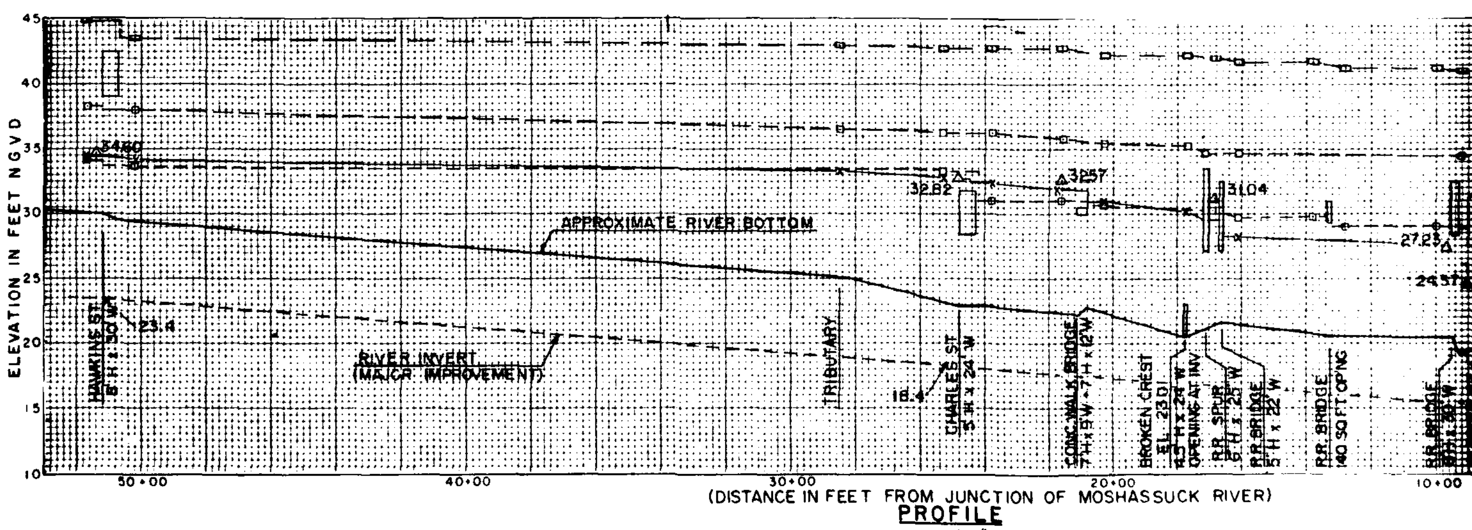
PLATE 6

2

CORPS OF ENGINEERS

ELEVATIONS ON PLAN
ARE CITY OF PROVIDENCE MEAN HIGH WATER
PROV. MHW + 2.75' = N.G.V. DATUM

PLAN
SCALE 1" = 200'

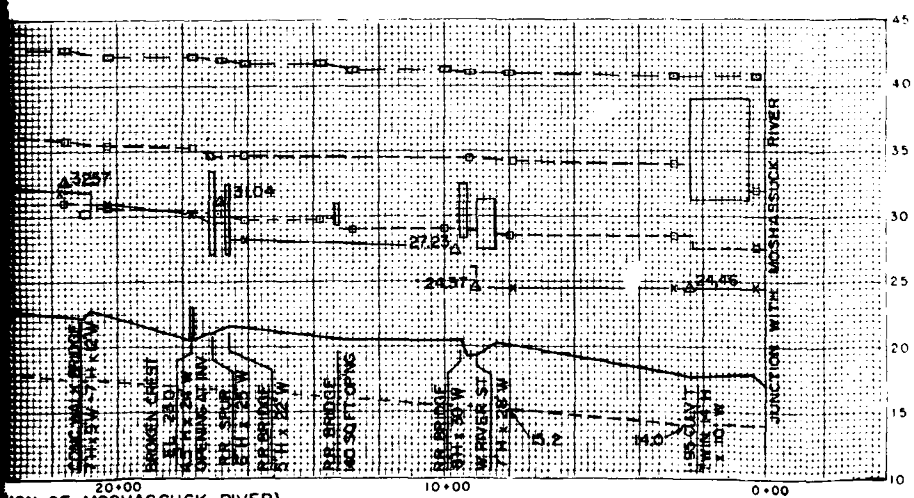


(DISTANCE IN FEET FROM JUNCTION OF MOSHASSUCK RIVER)

PROFILE
SCALE HOR 1" = 200'
VER 1" = 5'

D E F G H U. S. ARMY

PLAN
SCALE 1" = 200'



NOTES

1. PLAN ELEVATIONS ARE BASED ON MEAN HIGH WATER, CITY OF PROVIDENCE (PROV. M.H.W. DATUM +2.75 = N.G.V. DATUM)
2. HIGH WATER ELEVATIONS, JAN 1979

—x— JAN 1979 FLOOD COMPUTED
—— STANDARD PROJECT FLOOD
— — 100 YEAR FREQUENCY FLOOD
— — 100 YEAR FREQUENCY FLOOD (MAJOR IMPROVEMENT)
APPROXIMATE 100-YR FLOOD PLAIN

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

PAWCATUCK RIVER–NARRAGANSETT BAY DRAINAGE BASIN
WATER RESOURCES INVESTIGATION
WEST RIVER
PLAN & PROFILE NO. W-1

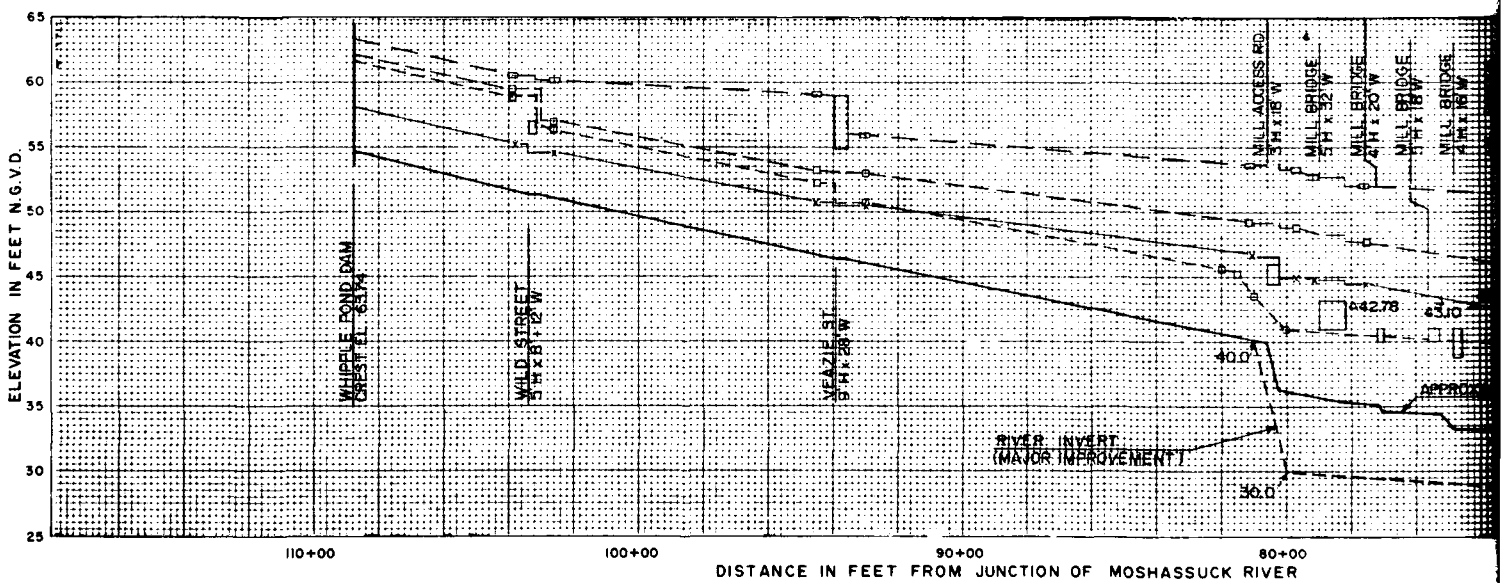
HYDRO ENG SECT 1980

APPROVED DATE
CHIEF, ENGINEERING DIVISION
SCALE SPEC NO.
DRAWING NUMBER
SHEET

PLATE 7

CORPS OF ENGINEERS

PLAN
SCALE 1" = 200'



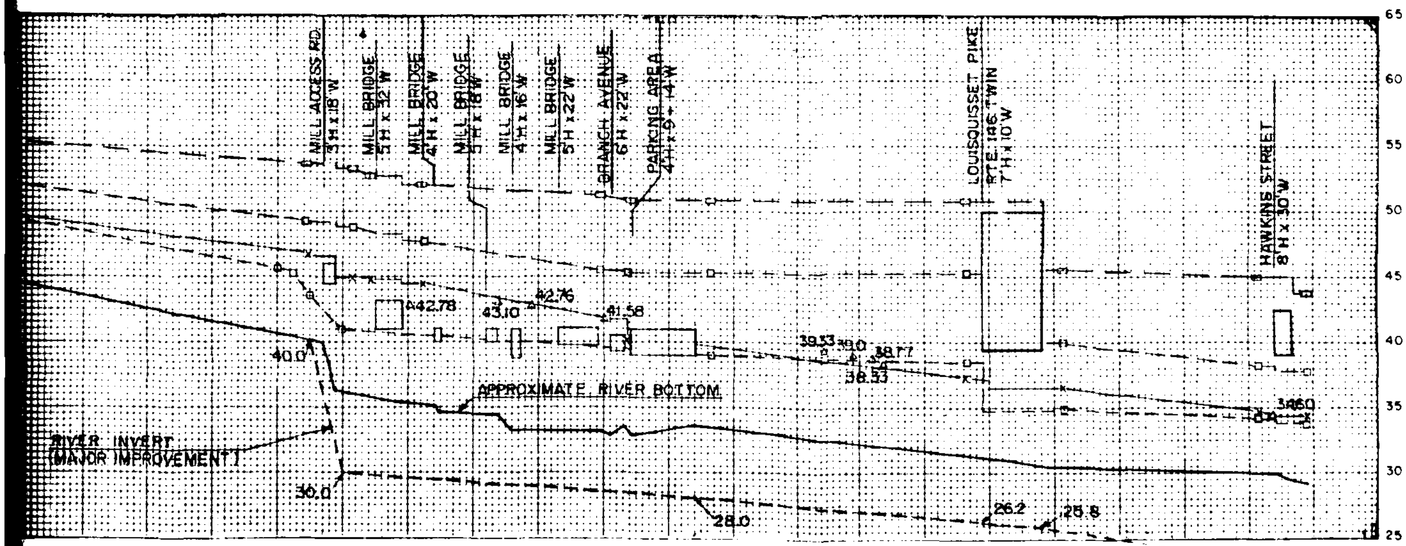
PROFILE
SCALE: HOR. 1" = 200'
VERT. 1" = 5'

U.S. ARMY

ELEVATIONS ON PLAN
ARE CITY OF PROVIDENCE MEAN HIGH WATER
PROV. MHW + 2.75' = N.G.V. DATUM

PLAN

SCALE 1" = 200'



JUNCTION OF MOSHASSUCK RIVER

234

PROFILE

SCALE: HOR. 1" = 200'
VERT. 1" = 5'

NOTES:

1. ELEVATIONS ON PLAN ARE CITY OF PROVIDENCE MEAN HIGH WATER (PROV. M.H.W. DATUM + 2.75' = NGV DATUM)
2. △ HIGH WATER ELEVATION JAN. 1979

JAN. 1979 FLOOD COMPUTED
STANDARD PROJECT FLOOD
100 YEAR FREQUENCY FLOOD
100 YEAR FREQUENCY FLOOD (MAJOR IMPROVEMENTS)
APPROXIMATE 100 YR FLOOD PLAIN

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

DES. BY	DR. BY	CK. BY

SUBMITTED: CHIEF, SECTION
APPROVAL RECOMMENDED: CHIEF, BRANCH
REVIEWED: PROJECT
APPROVAL RECOMMENDED: CHIEF, BRANCH

PAWCATUCK RIVER - NARRAGANSETT BAY DRAINAGE BASIN

WATER RESOURCES INVESTIGATION

WEST RIVER

PLAN & PROFILE NO. W-2

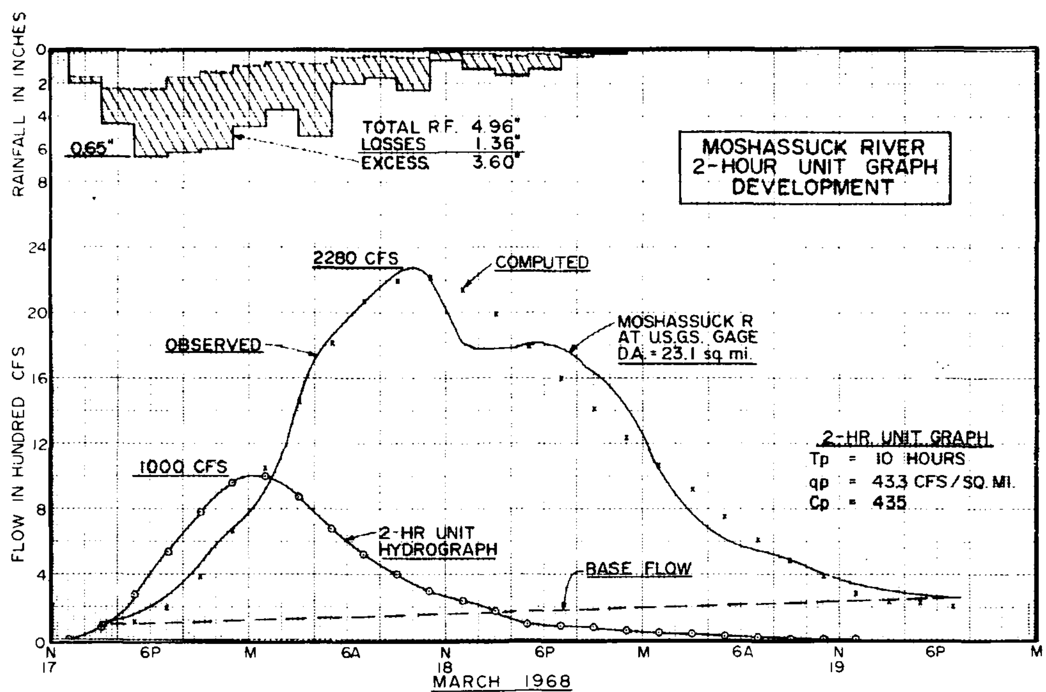
HYDRO ENG SECT 1980

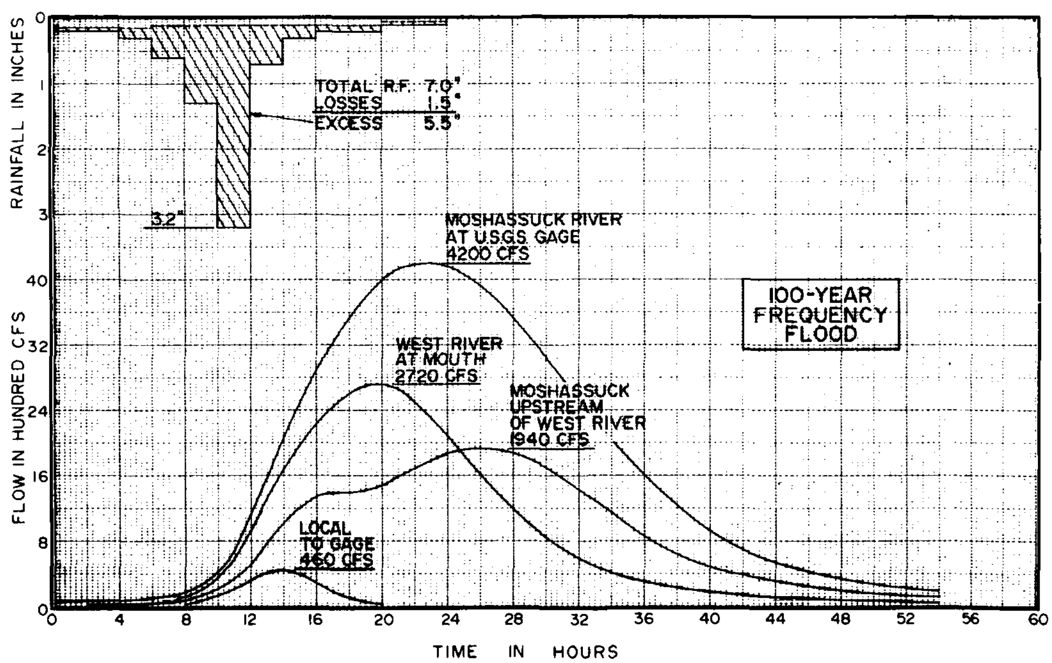
APPROVED: CHIEF, ENGINEERING DIVISION DATE

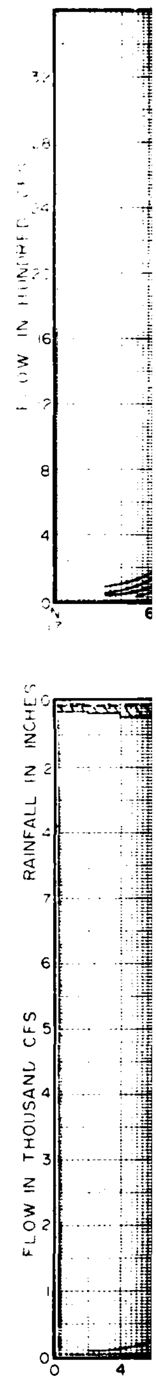
SCALE | SPEC. NO. | DRAWING NUMBER | SHEET

PLATE 8

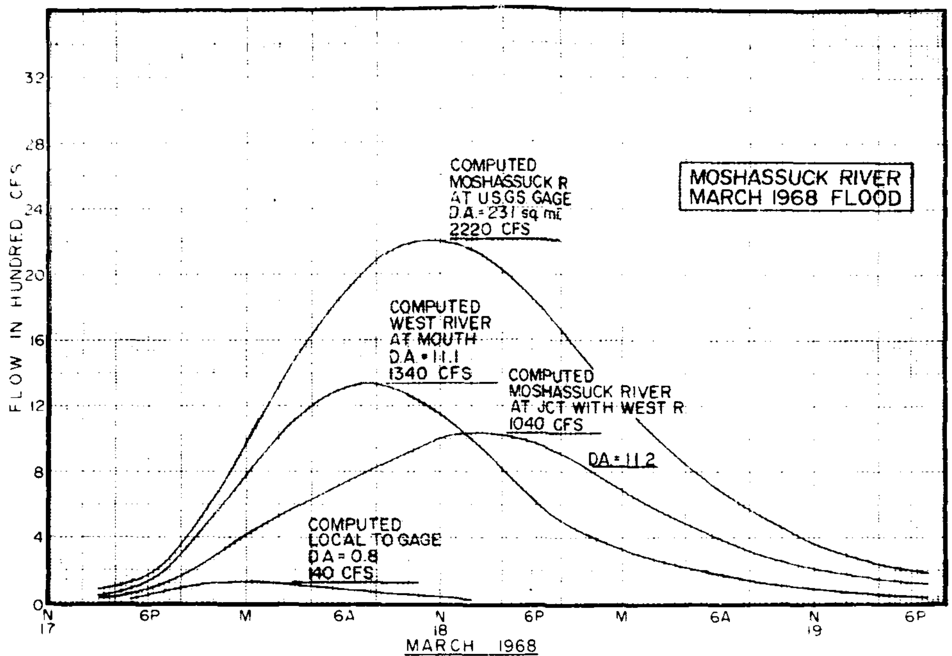
2

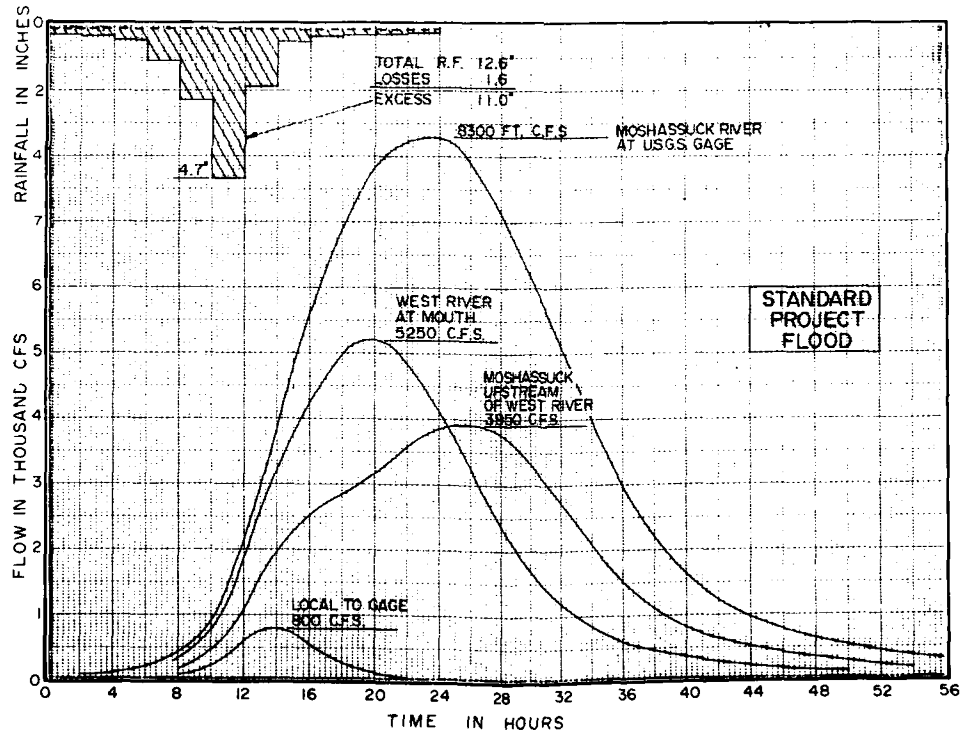

MOSHASSUCK RIVER
2-HOUR UNIT GRAPH
DEVELOPMENT
RAINFALL IN INCHES
TOTAL R.F. 4.96"
LOSSES 1.36"
EXCESS 3.60"
0.65"
FLOW IN HUNDRED CFS
2280 CFS
COMPUTED
OBSERVED
MOSHASSUCK R
AT U.S.G.S. GAGE
D.A. = 23.1 sq. mi.
1000 CFS
2-HR. UNIT GRAPH
Tp = 10 HOURS
qp = 43.3 CFS/SQ. MI.
Cp = 435
2-HR UNIT
HYDROGRAPH
BASE FLOW
N 17
6P
M
6A
N 18
6P
M
6A
N 19
6P
M
MARCH 1968


RAINFALL IN INCHES
TOTAL R.F. 7.0"
LOSSES 1.5"
EXCESS 5.5"
3.2"
FLOW IN HUNDRED CFS
MOSHASSUCK RIVER
AT U.S.G.S. GAGE
4200 CFS
100-YEAR
FREQUENCY
FLOOD
WEST RIVER
AT MOUTH
2720 CFS
MOSHASSUCK
UPSTREAM
OF WEST RIVER
1940 CFS
LOCAL
TO GAGE
460 CFS
TIME IN HOURS


RAINFALL IN INCHES
FLOW IN THOUSAND CFS

D E F G H U. S. ARMY





DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

PAWCATUCK RIVER-NARRAGANSETT BAY DRAINAGE BASIN
WATER RESOURCES INVESTIGATION
MOSHASSUCK RIVER
FLOOD HYDROGRAPHS

MOSHASSUCK R., RHODE ISLAND NOVEMBER, 1980

DES BY | DR BY | CK BY
SUBMITTED
CHIEF SECTION
APPROVAL RECOMMENDED
CHIEF, DESIGN BRANCH
REVIEWED
PROJECT ENGINEER
APPROVAL RECOMMENDED
CHIEF BRANCH
APPROVED DATE
CHIEF, ENGINEERING DIVISION
SCALE | SPEC NO
DRAWING NUMBER
SHEET

PLATE 9

2

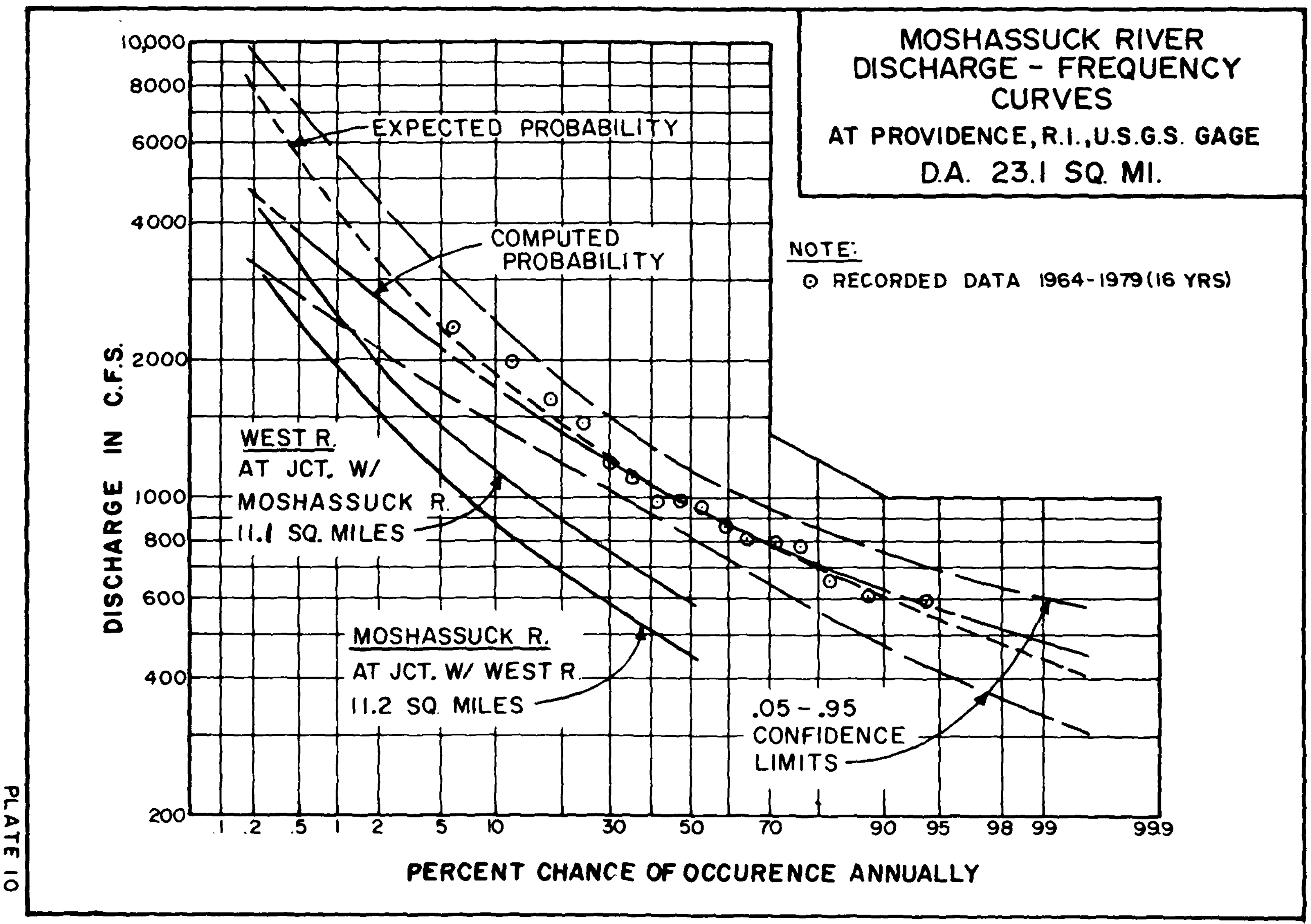
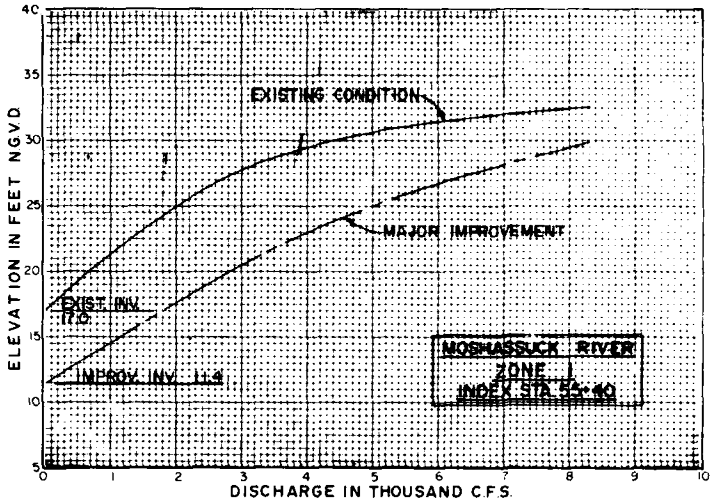
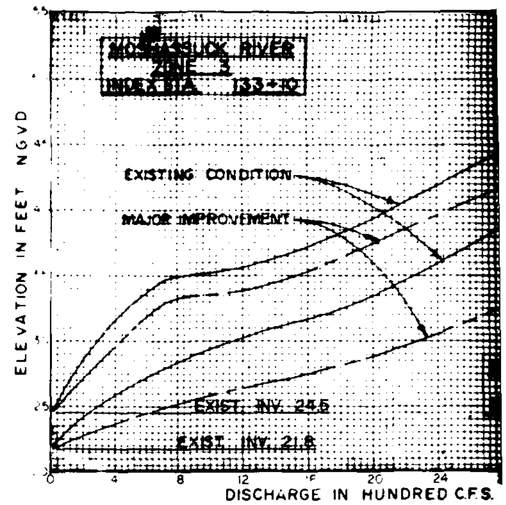
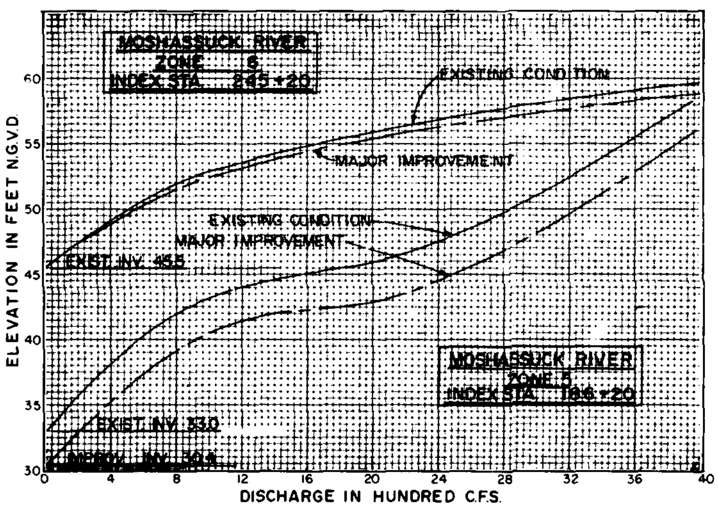
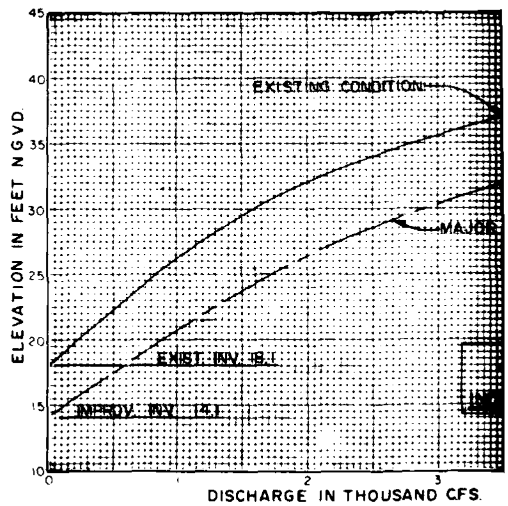

MOSHASSUCK RIVER
DISCHARGE - FREQUENCY
CURVES
AT PROVIDENCE, R.I., U.S.G.S. GAGE
D.A. 23.1 SQ. MI.
NOTE:
⊙ RECORDED DATA 1964-1979 (16 YRS)
EXPECTED PROBABILITY
COMPUTED
PROBABILITY
WEST R.
AT JCT. W/
MOSHASSUCK R.
11.1 SQ. MILES
MOSHASSUCK R.
AT JCT. W/ WEST R.
11.2 SQ. MILES
.05 - .95
CONFIDENCE
LIMITS
DISCHARGE IN C.F.S.
10,000
8000
6000
4000
2000
1000
800
600
400
200
.1 .2 .5 1 2 5 10 30 50 70 90 95 98 99 99.9
PERCENT CHANCE OF OCCURENCE ANNUALLY

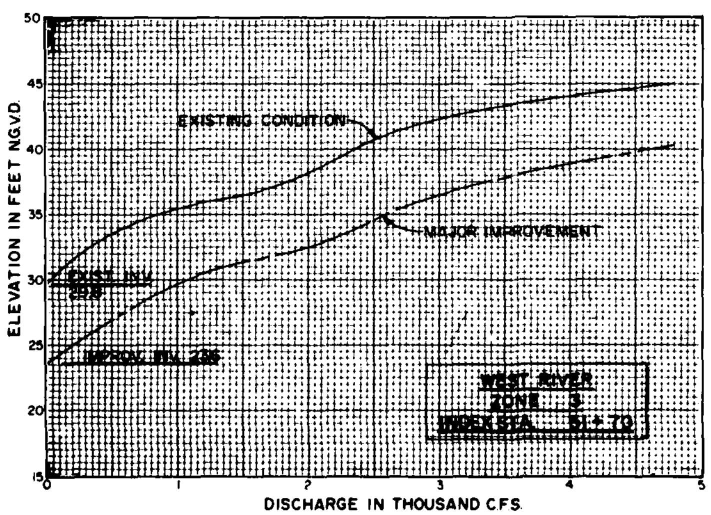
PLATE 10

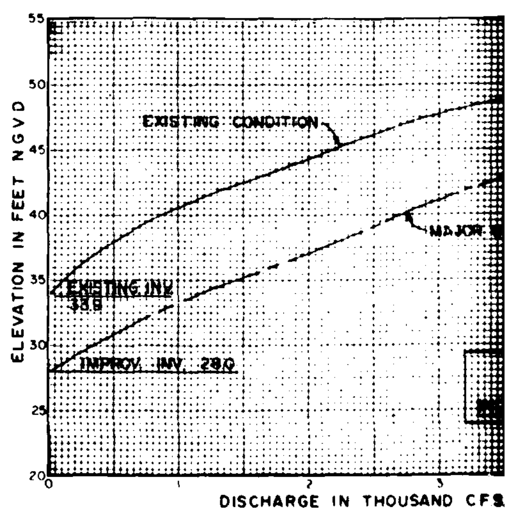

EXISTING CONDITION
MAJOR IMPROVEMENT
EXIST. INV. 17.0
IMPROV. INV. 11.4
MOSHASSUCK RIVER
ZONE 1
INDEX STA. 55+40
ELEVATION IN FEET NGVD
DISCHARGE IN THOUSAND C.F.S.

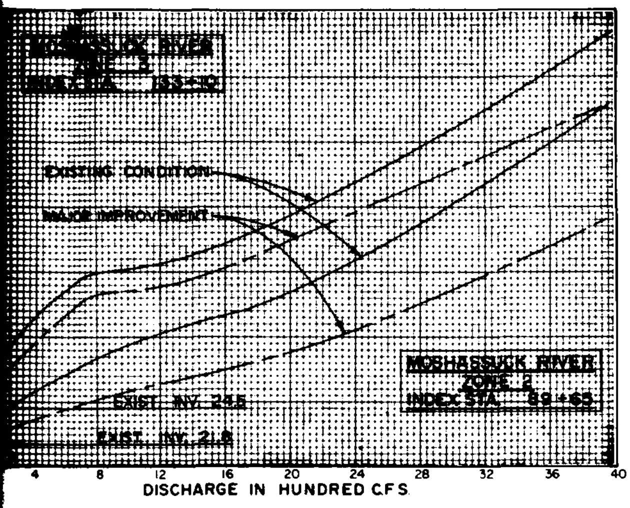

MOSHASSUCK RIVER
ZONE 3
INDEX STA. 133+10
EXISTING CONDITION
MAJOR IMPROVEMENT
EXIST. INV. 24.5
EXIST. INV. 21.6
ELEVATION IN FEET NGVD
DISCHARGE IN HUNDRED C.F.S.

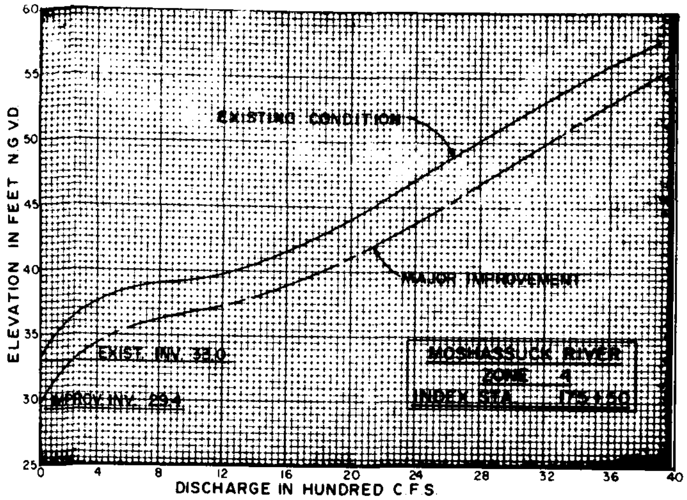

MOSHASSUCK RIVER
ZONE 6
INDEX STA. 245+20
EXISTING CONDITION
MAJOR IMPROVEMENT
EXISTING CONDITION
MAJOR IMPROVEMENT
EXIST. INV. 45.5
EXIST. INV. 33.0
MOSHASSUCK RIVER
ZONE 5
INDEX STA. 186+20
ELEVATION IN FEET N.G.V.D.
DISCHARGE IN HUNDRED C.F.S.

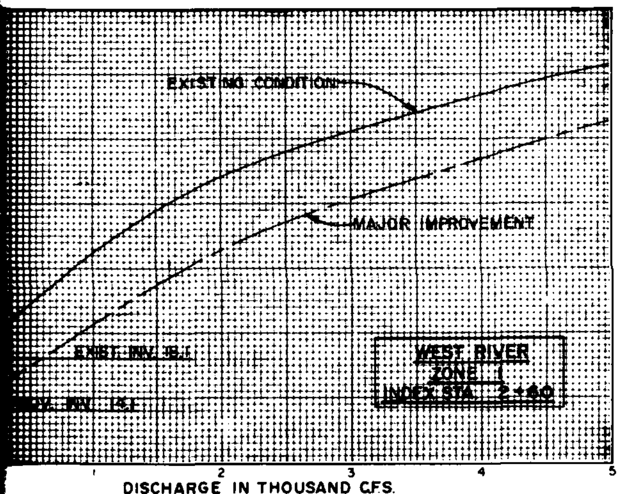

EXISTING CONDITION
EXIST. INV. 18.1
IMPROV. INV. 14.1
ELEVATION IN FEET NGVD
DISCHARGE IN THOUSAND CFS.

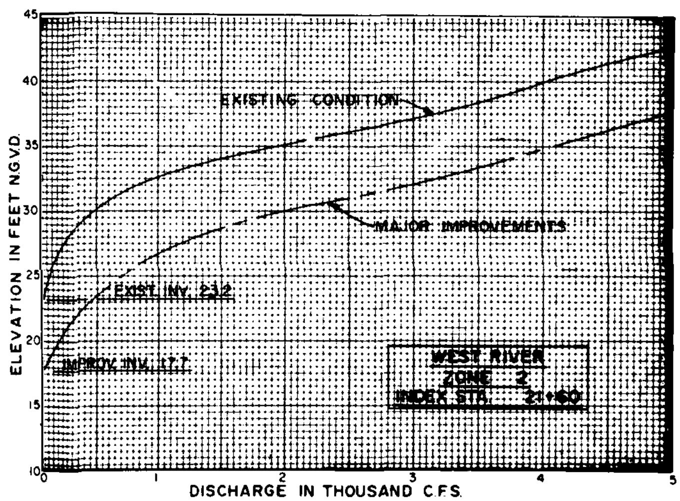

EXISTING CONDITION
MAJOR IMPROVEMENT
EXIST. INV. 29.8
IMPROV. INV. 23.6
WEST RIVER
ZONE 3
INDEX STA. 51+70
ELEVATION IN FEET NGVD.
DISCHARGE IN THOUSAND C.F.S.

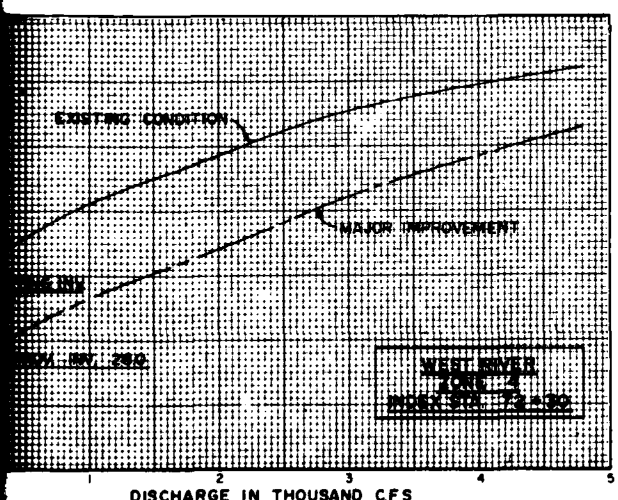

EXISTING CONDITION
EXISTING INV. 33.9
IMPROV. INV. 28.0
ELEVATION IN FEET NGVD
DISCHARGE IN THOUSAND CFS.











SAFETY PAYS

REVISION	DATE	DESCRIPTION	BY

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

PAWCATUCK RIVER - NARRAGANSETT BAY DRAINAGE BASIN
WATER RESOURCES INVESTIGATION
MOSHASSUCK AND WEST RIVERS
DISCHARGE RATING CURVES

HYDRO ENG SECT 1981

SHEET

PLATE 11

2

LISTING, HEC-1 COMPUTER INPUT DATA
MARCH 1968 FLOOD

```
          RIVER BASIN SIMILATION PROGRAM
          MOSHASSUCK      RIVER BASIN
          MARCH 17-18 1968 STORM FLOOD
   27        2        0      017       13        0        0        0        2       21
    3        0
    1        5
    2        5
    3        5
    4        5
    5        5
    6        5
    7        5
    8        5
    9        5
   10        5
   11        5
   12        5
   13        5
   14        5
   15        5
   16        5
   17        5
   18        5
   19        5
   20        5
   21        5
    1       27
  1??
  .2?      .45      .65      .62      .60      .46      .36      .52      .20      .17
  .?4      .06      .11      .15      .11      .03      .02      .01      .00      .00
  .00      .00      .00      .00      .00      .00      .00
    0        1        0        0        0        0        1
          RUNOFF FROM SUBAREA NO 1  MOSHASSUCK RIVER
    2        2     1.34
    1        1
    1        1
  100        1
    0        0        0        0        0        0       .5      .04       .1      .25
 4.47      .48        0
 -4.0     -0.1      9.0
    0        2        0        0        0        0        1
          RUNOFF FROM SUBAREA NO 2  MOSHASSUCK RIVER
    2        2     1.01
    1        1
    2        1
  100        1
    0        0        0        0        0        0       .5      .04       .1      .25
 ?.16      .68        0
 -4.0     -0.1      9.0
    0        3        0        0        0        0        1
          RUNOFF FROM SUBAREA NO 3  MOSHASSUCK RIVER
    2        2     0.52
    1        1
    ?        1
  ???        1
```

```
T      0      0      0      0      0      0     .5    .04    .1    .25
W   3.91    .68      0
X   -4.0   -0.1    9.0
K      3      3      0      0      0      0      1
1         FLOW FROM AREA 1 2 3  AT LOCATION NO 3
K      1      5      0      0      0      0      1
1         SUBAREA FLOW 1-2-3 ROUTED 3/1 TO LOCATION NO 5 \ MOSHASSUCK *
Y      0      0      0      0      0
Z      1      3      1
K      0      4      0      0      0      0      1
1         RUNOFF FROM SUBAREA NO 4  MOSHASSUCK RIVER
M      2      2   1.18
O      1      1
1      4      1
2    100      1
T      0      0      0      0      0      0     .5    .04    .1    .25
W   3.50    .68      0
X   -4.0   -0.1    9.0
K      0      5      0      0      0      0      1
1         RUNOFF FROM SUBAREA NO 5  MOSHASSUCK RIVER
M      2      2   0.57
O      1      1
1      5      1
2    100      1
T      0      0      0      0      0      0     .5    .04    .1    .25
W   3.50    .68      0
X   -4.0   -0.1    9.0
K      0      6      0      0      0      0      1
1         RUNOFF FROM SUBAREA NO 6  MOSHASSUCK RIVER
M      2      2   0.85
O      1      1
1      6      1
2    100      1
T      0      0      0      0      0      0     .5    .04    .1    .25
W   3.50    .68      0
X   -4.0   -0.1    9.0
K      4      6      0      0      0      0      1
1         TOTAL   FLOW 1 THRU 6 AT LOCATION NO 6 \ MOSHASSUCK *
K      1      6      0      0      0      0      1
1         FLOW AT LOCATION NO 6 ROUTED THRU BUTTERFLY POND \ MOSHASSUCK *
Y                           1
1      1                                         8
2      8     20     50     80    100    150
3      0    160    450    830   1280   3000
K      0      7      0      0      0      0      1
1         RUNOFF FROM SUBAREA NO 7  MOSHASSUCK RIVER
M      2      2    .79
O      1      1
1      7      1
2    100      1
T      0      0      0      0      0      0     .5    .04    .1    .25
W   3.80    .68      0
X   -4.0   -0.1    9.0
K      1      8      0      0      0      0      1
1         FLOW AT LOCATION NO 7 ROUTED THRU OLNEY POND TO LOCATION NO 8
Y                           1
1      1                                        10
2     10     20     50     80    100    150
3     10     30     70    100    500   1200
K      0      8      0      0      0      0      1
1         RUNOFF FROM SUBAREA NO 8  MOSHASSUCK RIVER
```

```
M       2       2    0.72
O       1       1
1       8       1
2     100       1
T       0       0       0       0       0       0      .5     .04      .1     .25
W    3.20     .68       0
X    -4.0    -0.1     9.0
K       3       8       0       0       0       0       1
1          TOTAL FLOW 1 THRU 8 AT LOCATION NO 8    BARNEY RESERVOIR \ MOSHASSUCK *
K       1       8       0       0       0       0       1
1          FLOW AT LOCATION NO 8    ROUTED THRU BARNEY RESERVOIR \ MOSHASSUCK *
Y                               1
1       1                                               8
2       8      20      50      85     120     160     200     240     300
3       0      20     120     280     480     700     960    2500    4000
K       0       9       0       0       0       0       1
1          RUNOFF FROM SUBAREA NO 9  MOSHASSUCK RIVER
M       2       2    0.10
O       1       1
1       9       1
2     100       1
T       0       0       0       0       0       0      .5     .04      .1     .25
W    1.81     .58       0
X    -4.0    -0.1     9.0
K       2       9       0       0       0       0       1
1          TOTAL FLOW FROM   1 THRU 9   INFLOW TO BLEACHERY POND  \MOSHASSUCK *
K       1       9       0       0       0       0       1
1          FLOW AT LOCATION NO 9 ROUTED THRU BLEACHERY POND \ MOSHASSUCK *
Y                               1
1       1                                               5
2       5      50      65      80     100
3       0     500    2200    2900    3600
K       1      10       0       0       0       0       1
1          OUTFLOW FROM BLEACHERY POND ROUTED 3/1 TO NO 10 \ MOSHASSUCK *
Y       0       0       0       0       0
1       1       3       1
K       0      10       0       0       0       0       1
1          RUNOFF FROM SUBAREA NO 10  MOSHASSUCK RIVER
M       2       2    0.97
O       1       1
1      10       1
2     100       1
T       0       0       0       0       0       0      .5     .04      .1     .25
W    3.24     .68       0
X    -4.0    -0.1     9.0
K       2      10       0       0       0       0       1
1          TOTAL FLOW FROM  1 THRU 10   AT LOCATION NO 10 \ MOSHASSUCK *
K       1      10       0       0       0       0       1
1          FLOW AT LOCATION NO 10 ROUTED 5/2 TO LOCATION NO 11 \ MOSHASSUCK *
Y       0       0       0       0       0
1       1       5       2
K       0      11       0       0       0       0       1
1          RUNOFF FROM SUBAREA NO 11  MOSHASSUCK RIVER
M       2       2    1.10
O       1       1
1      11       1
2     100       1
T       0       0       0       0       0       0      .5     .04      .1     .25
W    3.50     .68       0
X    -4.0    -0.1     9.0
K       2      11       0       0       0       0       1
```

```
1        TOTAL FLOW FROM  1 THRU 11  AT  LOCATION NO 11 \ MOSHASSUCK *
.     1     12        0        0        0        0        1
1        FLOW AT LOCATION NO 11 ROUTED 5/2 TO LOCATION NO 12 \ MOSHASSUCK *
Y     0      0        0        0        0
1     1      5        2
K     0     12        0        0        0        0        1
1        RUNOFF FROM SUBAREA NO 12  MOSHASSUCK RIVER
M     2      2     1,72
O     1      1
1    12      1
2   100      1
T     0      0        0        0        0        0       ,5      ,04       ,1      ,25
W  4,16    ,68        0
X  -4,0   -0,1      9,0
K     2     12        0        0        0        0        1
1        TOTAL FLOW FROM  1 THRU 12 AT LOCATION NO 12 \ MOSHASSUCK *
K     0     13        0        0        0        0        1
1        RUNOFF FROM SUBAREA NO 13  WEST R
M     2      2     2,18
O     1      1
1    13      1
2   100      1
T     0      0        0        0        0        0       ,5      ,04       ,1      ,25
W  3,96    ,68        0
X  -4,0   -0,1      9,0
K     0     14        0        0        0        0        1
1        RUNOFF FROM SUBAREA NO 14  WEST R
M     2      2     0,89
O     1      1
1    14      1
2   100      1
T     0      0        0        0        0        0       ,5      ,04       ,1      ,25
W  1,69    ,68        0
X  -4,0   -0,1      9,0
K     2     14        0        0        0        0        1
1        TOTAL FLOW 13 + 14 AT LOCATION NO 14  WEST
K     1     14        0        0        0        0        1
1        FLOW AT LOCATION NO 14 ROUTED THRU WENSCOTT RESERVOIR \ MOSHASSUCK *
Y                              1
1     1                                          10
2    10     80      170      260      350
3     0    210      590     1100     1660
K     1     16        0        0        0        0        1
1        OUTFLOW FROM WENSCOTT RES ROUTED 3/2 TO LOCATION NO 16 WEST R
Y     0      0        0        0        0
1     1      3        2
K     0     15        0        0        0        0        1
1        RUNOFF FROM SUBAREA NO 15  WEST R
M     2      2     2,20
O     1      1
1    15      1
2   100      1
T     0      0        0        0        0        0       ,5      ,04       ,1      ,25
W  5,71    ,68        0
X  -4,0   -0,1      9,0
K     0     16        0        0        0        0        1
1        RUNOFF FROM SUBAREA NO 16  WEST R
M     2      2     2,20
O     1      1
1    16      1
2   100      1
```

```
T      0      0      0      0      0      0     .5    .04     .1    .25
W   3.80    .68      0
X   -4.0   -0.1    9.0
K      3     16      0      0      0      0      1
1          TOTAL FLOW FROM 13 THRU 16 AT LOCATION NO 16
K      1     18      0      0      0      0      1
1          FLOW AT LOCATION NO 16 ROUTED 3/1 TO LOCATION NO 18  WEST R
Y      0      0      0      0      0
1      1      3      1
K      0     17      0      0      0      0      1
1          RUNOFF FROM SUBAREA NO 17  WEST R
M      2      2   1.60
O      1      1
1     17      1
2    100      1
T      0      0      0      0      0      0     .5    .04     .1    .25
W   4.30    .68      0
X   -4.0   -0.1    9.0
K      1     18      0      0      0      0      1
1          FLOW FROM LOCATION 17 ROUTED THRU CANADA POND TO LOCATION NO 18  WEST R
Y                           1
1      1                                         2
2      2      0     24     50     75    100
3      0     10    240    360    620    840
K      0     18      0      0      0      0      1
1          RUNOFF FROM SUBAREA NO 18  WEST R
M      2      2   1.20
O      1      1
1     18      1
2    100      1
T      0      0      0      0      0      0     .5    .04     .1    .25
W   2.85    .68      0
X   -4.0   -0.1    9.0
K      3     18      0      0      0      0      1
1          TOTAL FLOW FROM 13 THRU 18 AT LOCATION NO 18  WEST R
K      1     19      0      0      0      0      1
1          FLOW AT LOCATION NO 18 ROUTED 3/1 TO LOCATION NO 19 WEST R
Y      0      0      0      0      0
1      1      3      1
K      0     19      0      0      0      0      1
1          RUNOFF FROM SUBAREA NO 19  WEST R
M      2      2   0.83
G      1      1
1     19      1
2    100      1
T      0      0      0      0      0      0     .5    .04     .1    .25
W   2.55    .68      0
X   -4.0   -0.1    9.0
K      2     19      0      0      0      0      1
1          TOTAL FLOW 13 THRU 19 WEST RIVER
K      2     19      0      0      0      0      1
1          TOTAL FLOW FROM 1 THRU 19 AT LOCATION NO 19 MOSHASSUCK R
K      1     20      0      0      0      0      1
1          FLOW AT LOCATION NO 19  ROUTED  3/1  TO LOCATION NO 20 \ USGS GAGE *
Y      0      0      0      0      0
1      1      3      1
K      0     20      0      0      0      0      1
1          RUNOFF FROM SUBAREA NO 20  MOSHASSUCK R
M      2      2   0.83
O      1      1
1     20      1
```

```
2      100        1
T        0        0        0        0        0        0       .5      .04       .1      .25
W     2.74      .68        0
X     -4.0     -0.1      9.0
K        2       20        0        0        0        0        1
1          TOTAL FLOW FROM 1 THRU 20 AT LOCATION NO 20 \USGS GAGE* MOSHASSUCK
K        1       21        0        0        0        0        1
1          FLOW AT LOCATION NO 20 ROUTED  3/1  TO  LOCATION NO 21 MOSHASSUCK
Y        0        0        0        0        0
1        1        3        1
K        0       21        0        0        0        0        1
1          RUNOFF FROM SUBAREA NO 21  MOSHASSUCK R
M        2        2     0.20
0        1        1
1       21        1
2      100        1
T        0        0        0        0        0        0       .5      .04       .1      .25
W     2.05      .68        0
X     -4.0     -0.1      9.0
K        2       21        0        0        0        0        1
1          TOTAL FLOW FROM 1 THRU 21 AT LOCATION NO 21  MOSHASSUCK R
K       99
A
A
A
A
A
                                                                        **
```

MARCH 1968 FLOOD

RUNOFF SUMMARY, AVERAGE FLOW

		PEAK	6-HOUR	24-HOUR	72-HOUR	AREA
HYDROGRAPH AT	1	197.75	192.21	125.65	62.39	1.34
HYDROGRAPH AT	2	155.71	147.48	95.37	47.17	1.01
HYDROGRAPH AT	3	85.01	80.81	49.64	24.39	.52
3 COMBINED	3	438.21	416.08	270.23	135.90	2.87
ROUTED TO	5	416.08	404.59	267.21	134.29	2.87
HYDROGRAPH AT	4	191.62	182.19	112.03	55.33	1.18
HYDROGRAPH AT	5	141.43	134.32	82.60	40.79	.87
HYDROGRAPH AT	6	138.17	131.24	80.70	39.85	.85
4 COMBINED	6	840.04	821.81	540.98	270.26	5.77
ROUTED TO	6	843.45	812.20	537.02	270.63	5.77
HYDROGRAPH AT	7	128.76	121.94	75.07	37.03	.79
ROUTED TO	8	81.44	80.35	65.25	37.66	.79
HYDROGRAPH AT	8	116.95	111.35	68.61	33.80	.72
3 COMBINED	8	1018.06	965.50	666.55	342.09	7.28
ROUTED TO	8	983.05	945.22	651.76	339.95	7.28
HYDROGRAPH AT	9	17.79	16.79	9.69	4.76	.10
2 COMBINED	9	995.12	956.61	659.07	344.71	7.38
ROUTED TO	9	977.47	962.58	658.25	344.37	7.38
ROUTED TO	10	962.59	929.44	651.37	343.66	7.38
HYDROGRAPH AT	10	157.40	149.94	92.36	45.51	.97
2 COMBINED	10	1074.09	1024.77	721.84	369.17	8.35
ROUTED TO	10	967.75	966.58	703.05	366.93	8.35
HYDROGRAPH AT	11	178.81	169.83	104.44	51.57	1.10
2 COMBINED	11	1030.69	1011.99	769.01	438.51	9.45
ROUTED TO	12	972.06	953.31	751.69	434.41	9.45
HYDROGRAPH AT	12	265.17	251.49	162.41	80.32	1.72
2 COMBINED	12	1039.95	1023.44	846.50	514.73	11.17
HYDROGRAPH AT	13	348.25	329.78	206.81	102.07	2.18
HYDROGRAPH AT	14	158.55	149.85	86.38	42.49	.89
2 COMBINED	14	485.69	462.98	291.89	144.56	3.07
ROUTED TO	14	423.78	413.03	279.65	144.38	3.07
ROUTED TO	16	413.03	403.41	276.61	144.29	3.07
HYDROGRAPH AT	15	303.33	294.75	201.78	101.67	2.20
HYDROGRAPH AT	16	358.58	339.57	209.05	103.13	2.20
3 COMBINED	16	954.47	939.84	670.02	349.29	7.47
ROUTED TO	18	939.54	919.73	662.62	349.52	7.47
HYDROGRAPH AT	17	239.03	230.63	150.37	74.58	1.60
ROUTED TO	18	237.10	228.23	149.22	74.57	1.60
HYDROGRAPH AT	18	200.26	187.89	114.99	56.44	1.20
3 COMBINED	18	[illegible]	1249.33	912.80	480.53	10.27
ROUTED TO	19	1249.33	1225.39	903.21	480.79	10.27
HYDROGRAPH AT	19	143.92	134.95	79.93	39.19	.83
2 COMBINED	19	1336.99	1303.04	967.45	519.99	11.10
2 COMBINED	19	2197.80	2170.64	1778.46	1034.72	22.27
ROUTED TO	20	2170.64	2141.54	1762.93	1031.80	22.27
HYDROGRAPH AT	20	140.41	131.58	79.47	38.96	.83
2 COMBINED	20	2211.87	2186.21	1808.57	1070.78	23.10
ROUTED TO	21	2186.21	2160.40	1793.07	1066.70	23.10
HYDROGRAPH AT	21	35.53	33.42	19.34	9.49	.20
2 COMBINED	21	2193.33	2166.86	1802.73	1076.19	23.30

INCLOSURE 2

100-YEAR SYNTHETIC FLOOD

RUNOFF SUMMARY, AVERAGE FLOW

		PEAK	6-HOUR	24-HOUR	72-HOUR	AREA
HYDROGRAPH AT	1	544.95	479.25	201.14	94.90	1.34
HYDROGRAPH AT	2	427.30	374.52	152.76	71.79	1.01
HYDROGRAPH AT	3	273.27	220.44	80.63	37.82	.52
3 COMBINED	3	1164.90	1037.74	434.53	204.51	2.87
ROUTED TO	5	1037.74	946.34	432.63	204.77	2.87
HYDROGRAPH AT	4	576.53	475.80	181.15	84.93	1.16
HYDROGRAPH AT	5	425.07	350.80	133.56	62.62	.87
HYDROGRAPH AT	6	415.29	342.74	130.49	61.16	.85
4 COMBINED	6	2213.22	1999.26	876.05	413.50	5.77
ROUTED TO	6	2238.36	2017.15	874.34	413.78	5.77
HYDROGRAPH AT	7	363.21	308.22	121.18	56.74	.79
ROUTED TO	8	353.58	242.39	111.61	57.34	.79
HYDROGRAPH AT	8	367.06	298.43	111.20	52.18	.72
3 COMBINED	8	2871.08	2509.96	1093.86	523.30	7.28
ROUTED TO	8	3002.09	2421.92	1080.08	521.02	7.28
HYDROGRAPH AT	9	57.80	45.86	15.71	7.32	.10
2 COMBINED	9	3021.51	2449.43	1093.39	526.54	7.38
ROUTED TO	9	2883.54	2453.10	1091.95	527.96	7.38
ROUTED TO	10	2453.10	2157.70	1083.64	527.16	7.38
HYDROGRAPH AT	10	491.40	400.15	149.62	70.21	.97
2 COMBINED	10	2536.37	2373.46	1216.44	597.37	8.35
ROUTED TO	10	2029.58	1936.89	1165.24	594.63	8.35
HYDROGRAPH AT	11	537.44	443.54	168.87	79.17	1.10
2 COMBINED	11	2083.17	2005.69	1319.80	674.00	9.45
ROUTED TO	12	1876.66	1830.58	1284.24	669.47	9.45
HYDROGRAPH AT	12	727.68	637.80	260.15	122.25	1.72
2 COMBINED	12	1936.23	1891.32	1479.61	791.72	11.17
HYDROGRAPH AT	13	940.28	829.70	332.91	156.07	2.18
HYDROGRAPH AT	14	545.83	420.43	141.14	65.86	.89
2 COMBINED	14	1447.19	1208.28	473.47	221.93	3.07
ROUTED TO	14	1148.40	1015.68	464.11	221.70	3.07
ROUTED TO	16	1015.68	926.92	461.04	221.52	3.07
HYDROGRAPH AT	15	763.98	687.11	322.68	153.07	2.20
HYDROGRAPH AT	16	1011.46	858.35	337.46	158.02	2.20
3 COMBINED	16	2233.04	2050.42	1108.21	532.61	7.47
ROUTED TO	18	2050.42	1952.16	1100.33	532.71	7.47
HYDROGRAPH AT	17	656.90	577.57	240.77	113.49	1.60
ROUTED TO	18	606.77	522.69	240.30	113.46	1.60
HYDROGRAPH AT	18	648.03	518.84	186.48	87.41	1.20
3 COMBINED	18	2797.76	2671.14	1517.34	733.58	10.27
ROUTED TO	19	2671.14	2553.26	1506.89	733.62	10.27
HYDROGRAPH AT	19	474.82	373.03	130.38	61.05	.83
2 COMBINED	19	2716.26	2610.08	1623.35	794.68	11.10
2 COMBINED	19	4232.63	4152.70	3077.92	1560.39	22.27
ROUTED TO	20	4152.70	4076.16	3041.27	1582.92	22.27
HYDROGRAPH AT	20	456.75	363.60	128.95	60.37	.83
2 COMBINED	20	4137.18	4113.24	3129.38	1643.29	23.10
ROUTED TO	21	4113.24	4059.69	3092.49	1636.55	23.10
HYDROGRAPH AT	21	117.14	90.92	31.40	14.65	.20
2 COMBINED	21	4119.45	4046.00	3101.34	1653.20	23.30

STANDARD PROJECT FLOOD

RUNOFF SUMMARY, AVERAGE FLOW

		PEAK	6-HOUR	24-HOUR	72-HOUR	AREA
HYDROGRAPH AT	1	997.	837.	394.	141.	1.34
HYDROGRAPH AT	2	783.	694.	299.	106.	1.01
HYDROGRAPH AT	3	441.	401.	155.	55.	0.52
3 COMBINED	3	2155.	1929.	847.	303.	2.47
ROUTED TO	5	1929.	1771.	843.	303.	2.47
HYDROGRAPH AT	4	1014.	864.	352.	125.	1.18
HYDROGRAPH AT	5	744.	637.	259.	92.	0.67
HYDROGRAPH AT	6	730.	622.	253.	90.	0.85
4 COMBINED	6	4100.	3715.	1706.	610.	5.77
ROUTED TO	6	4130.	3717.	1699.	611.	5.77
HYDROGRAPH AT	7	642.	565.	235.	85.	0.79
ROUTED TO	8	650.	563.	220.	84.	0.79
HYDROGRAPH AT	8	646.	543.	215.	77.	0.72
3 COMBINED	8	5515.	4779.	2129.	771.	7.28
ROUTED TO	8	5245.	4752.	2110.	771.	7.28
HYDROGRAPH AT	9	103.	83.	30.	11.	0.10
2 COMBINED	9	5291.	4807.	2139.	782.	7.38
ROUTED TO	9	5315.	4707.	2135.	782.	7.38
ROUTED TO	10	4707.	4294.	2118.	782.	7.38
HYDROGRAPH AT	10	865.	728.	290.	103.	0.97
2 COMBINED	10	5103.	4733.	2383.	885.	8.35
ROUTED TO	10	4113.	3926.	2334.	885.	8.35
HYDROGRAPH AT	11	945.	808.	328.	117.	1.10
2 COMBINED	11	4248.	4085.	2612.	1002.	9.45
ROUTED TO	12	3809.	3712.	2545.	1002.	9.45
HYDROGRAPH AT	12	1334.	1181.	509.	181.	1.72
2 COMBINED	12	3939.	3855.	2942.	1183.	11.17
HYDROGRAPH AT	13	1744.	1539.	648.	230.	2.18
HYDROGRAPH AT	14	920.	751.	269.	95.	0.89
2 COMBINED	14	2584.	2208.	915.	325.	3.07
ROUTED TO	14	2180.	1957.	899.	325.	3.07
ROUTED TO	16	1957.	1796.	893.	326.	3.07
HYDROGRAPH AT	15	1395.	1269.	634.	228.	2.20
HYDROGRAPH AT	16	1788.	1573.	654.	232.	2.20
3 COMBINED	16	4221.	3978.	2160.	786.	7.47
ROUTED TO	18	3978.	3790.	2144.	787.	7.47
HYDROGRAPH AT	17	1203.	1069.	471.	168.	1.60
ROUTED TO	18	1083.	936.	469.	168.	1.60
HYDROGRAPH AT	18	1141.	944.	360.	128.	1.20
3 COMBINED	18	5374.	5134.	2958.	1083.	10.27
ROUTED TO	19	5134.	4911.	2936.	1084.	10.27
HYDROGRAPH AT	19	834.	673.	250.	88.	0.83
2 COMBINED	19	5224.	5039.	3156.	1172.	11.10
2 COMBINED	19	8424.	8258.	6059.	2356.	22.27
ROUTED TO	20	8258.	8113.	5992.	2357.	22.27
HYDROGRAPH AT	20	804.	662.	249.	88.	0.83
2 COMBINED	20	8318.	8174.	6164.	2445.	23.10
ROUTED TO	21	8174.	8035.	6094.	2447.	23.10
HYDROGRAPH AT	21	207.	166.	61.	21.	0.20
2 COMBINED	21	8184.	8046.	6114.	2468.	23.30

INCLOSURE 4

APPENDIX 5
RECREATION & NATURAL RESOURCES

APPENDIX 5: RECREATION & NATURAL RESOURCES

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APPENDIX 5: RECREATION AND NATURAL RESOURCES

RHODE ISLAND RECREATION GOALS

The State of Rhode Island has identified the major concerns for recreation and natural resources in the Pawcatuck, Narragansett Bay region, with the detailed analysis found in the Plan for Recreation, Conservation and Open Space, June 1978. This plan also serves as Rhode Island's Statewide Comprehensive Outdoor Recreation Plan (SCORP). The most important high-lights of the plan are cited here, followed by a description of the recreation and fish and wildlife resources in the Woonasquatucket, Pawcatuck and Narragansett Bay drainage areas.

In the SCORP the following general goals were established to guide the formulation of all recreation and natural resources plans and implementation programs:

1. Provide for adequate and diverse recreational opportunities and facilities primarily to meet the needs of the State's residents while also attracting and serving visitors.

2. Preserve and protect open space so as to enhance the total quality of the environment.

3. Insure the sound use and development of appropriate land and water resources in Rhode Island for recreational purposes.

4. Recognize that Narragansett Bay is the State's most important natural feature and recreation resource.

5. Improve the capability of both public and private sectors to respond to recreational needs at both the community and regional levels within the State.

6. Utilize, to the greatest extent possible, the capabilities of the private sector in the outdoor recreational area.

7. Improve opportunities for water-oriented recreation by reducing pollution and controlling water quality in Rhode Island's water bodies.

In order to assess regional recreation and natural resource problems and needs, the State used a number of different survey techniques. Various questionnaires and phone calls were utilized in order to compile and understand the recreation needs and concerns of the State. These surveys yielded a number of general conclusions which form a framework for future recreation planning. Numerous activities were surveyed, with the five most popular by order of popularity being:

1. Saltwater swimming
2. Freshwater swimming

3. Sightseeing
4. Picnicking
5. Outdoor games

Rhode Island's most abundant recreation resource is its saltwater; providing swimming, fishing and boating. A person's income level has a direct effect on how many activities are engaged in, and accessibility and car ownership affect the extent of participation.

The surveys also provide valuable information on the supply and demand for recreation facilities. It was discovered that people usually travel to the closest available supply, implying that there is overcrowding of facilities in and around population centers. Also, people tend to travel shorter distances and tend to participate more if supply is close at hand. Surveys and models have shown that supply of recreation facilities in Rhode Island is distributed unevenly in relation to the demand. With the exception of tennis and picnicking it was revealed that there is a surplus of supply on a Statewide basis for the most popular activities. In addition, demand for a certain activity is affected by location of supply and also quality of facilities and fees charged.

Season and time of the year are other factors which affect selection of recreation activities, with the analysis showing an overwhelming preference for summer periods. The State of Rhode Island has identified a definite need for improvement in nonsummer participation rates, with ice skating continuing to be the most popular of winter activites. Other general conclusions of the surveys showed:

-- Young people tend to recreate more than other people, and they tend to participate in more strenuous activities.

-- Bicycling is growing in popularity and shows a significant potential for the future.

-- Boating is Rhode Island's fastest growing recreation activity.

-- In the West Metropolitan region, there is a deficiency of freshwater swimming.

The following are specific recommendations indicating the State of Rhode Island's commitment to appropriate development in an effort to improve recreational opportunities in the most deficient areas.

1. Provide freshwater swimming, principally in the West and East Metropolitan areas, not only to meet supply deficiencies, but also as a substitute for saltwater swimming deficiencies.

2. Meet statewide supply deficiencies in tennis, which are most acute in the West Metropolitan and Northeast regions.

3. Meet picnicking deficiencies in all regions, particularly the West Metropolitan and Northeast regions.

4. Develop a statewide system of trails with special emphasis on establishing recreational and commuter bikeways.

5. Initiate the development of presently owned State land and establish a priority program for acquiring those remaining parcels of land constituting the complete Bay Islands Park.

6. Identify, publicize, and protect areas of scenic, historical, and cultural interest for the large sightseeing population.

7. Improve public access to the shore to maximize the opportunities for saltwater related activities.

8. Provide for more balanced freshwater fishing activity through an expanded stocking and public information program.

9. Improve use opportunities at existing urban and metropolitan parks and develop additional neighborhood recreation areas.

10. Provide safe and accessible ice skating areas in the metropolitan parks system which are not in conflict with the efforts of the private sector.

11. In cooperation with the State of Massachusetts and affected local governments, begin implementation of a linear recreational and heritage system along the Blackstone River and Canal in accordance with the concepts established in the feasibility study and in a manner which is not in conflict with previously defined priorities.

12. Improve the accessibility of outdoor recreation programs to the handicapped by insuring that all new or substantially improved facilities are accessible and usable, and by modifying, to the extent feasible, selected existing State facilities.

OUTDOOR RECREATION RESOURCES

Woonasquatucket Drainage Area - The Woonasquatucket River basin has limited potential for outdoor recreation. Currently there are about 2600 acres of land (approximately 5.4 percent of the basin's total land area) devoted to recreation and conservation; this includes State and local parks, management areas, town forests, private camps and golf courses. Swimming and boating are two activities with large deficiencies due to the lack of readily accessible water area.

There are four State parks within the Woonasquatucket River basin. The largest of these is Lincoln Woods State Park in Lincoln, Rhode Island. This park surrounds Olney Pond and provides boating, swimming,

horseback riding, fishing, picnicking and game fields. The only boat ramp within the basin is located at Olney Pond. Other State Parks within the basin include Dyerville State Park in North Providence and Providence, Peter Randall State Park in North Providence and a State-owned forest and reservation just upstream of Stillwater Pond in Smithfield. There is one private campground located in Smithfield.

There are eight freshwater public beaches within the Woonasquatucket River basin. Two are located on Waterman Reservoir in Glocester, two are on Wenscott Reservoir in Smithfield, one on Olney Pond in Lincoln, one on Georgiaville Pond in Smithfield, one on Slack Reservoir and one on Mountaindale Reservoir in Smithfield.

There are four golf courses within the basin area. There is one private club in Glocester and public courses in Providence, North Providence and Lincoln.

Limited areas are stocked with trout for recreational fishing: Woonasquatucket River upstream of Stillwater Reservoir; Ninefoot Brook upstream of Waterman Reservoir; and Geneva Brook just downstream of Wenscott Reservoir. Along the river from Primrose Pond into Providence a segment of an abandoned railroad right-of-way is being leased by the State of Rhode Island for development of a trail.

Pawcatuck Drainage Area - The rural Pawcatuck River basin and adjacent coastal areas are characterized by dense forests, farms, open marshes, unspoiled streams and fragile barrier beaches. This is one of the most important areas in southeastern New England for swimming, boating, camping, picnicking, nature study, hiking, freshwater fishing and hunting. Almost 17 percent of the total basin land area (44,000 acres) is classified as conservation and recreation land, of which 90 percent (38,500 acres) is State owned.

The majority of the 44,000 acres of recreation and conservation land in the study area is made up of the Pachaug State Forest in Voluntown and various Rhode Island management areas. There are approximately 5,700 acres of privately owned recreation lands (camps, clubs, and campgrounds) and only 10 acres of locally owned conservation and recreation lands. These resources are adequate to satisfy the future demands of the area residents for hiking, nature study and photography, and a large portion of the demand for camping.

Another potential pressure on recreational resources in the Pawcatuck planning area is a proposed water supply reservoir for the Providence Metropolitan area. The Wood River Reservoir could take 40 percent (3,000 acres) of the Arcadia State Management Area. Plans should be made to compensate for this taking, should it occur, to meet demands of tourists and urban dwellers for camping, picnicking and extensive outdoor recreation.

Narragansett Bay Drainage Area - Narragansett Bay , Rhode Island's greatest natural resource, is a focal point for population growth, recreation, commerce and fishing. The bay has many islands; the two largest, Aquidneck and Conanicut are much more heavily developed than Prudence Island which, unlike the others has no highway access. These three large islands and many smaller ones, and the numerous coves and estuaries, make the bay a haven for recreational boating, swimming, saltwater fishing, camping, picnicking, extensive outdoor recreation, and wildlife and fisheries production.

As indicated by the Southeastern New England Study, prepared by the New England River Basin's Commission, recreational resources of Narragansett Bay will increasingly be pressured by the rapidly growing population within this planning area and adjacent ones. Narragansett Bay accommodates recreational demand from the Providence Metropolitan Area, only a part of which is actually in the planning area. Because 75 percent of the planning area is open space (forest, field, open water, wetland) many of these demands could be met with the planning area's resources. There are over 10,000 acres of conservation and recreation lands, of which 5,900 acres are privately owned, 2,600 of which are State owned, and 1,500 of which are locally owned. This total represents about 5 percent of the total land in the planning area.

The Narragansett Bay shoreline is a combination of small pocket and large regional beaches, including Scarborough State Beach, Conimicut Island Park State Beach, Sachuset and Newport. Other shoreline areas, even where no beach exists, also have recreational value. Some areas are excellent for fishing, while many others have scenic value and are suitable for overlooks, picnic areas and parks. Existing parks around Narragansett Bay include Goddard, Colt, and Haines, and a park at Fort Adams overlooking Newport Harbor is currently under development. In addition, there are several State and Audubon wildlife preserves along with State piers and fishing access points scattered around the Bay.

Picnicking, camping and extensive outdoor recreation play important roles in the Narragansett Bay area's recreational scene. At present, the remaining natural islands of Narragansett Bay are, for the most part, undeveloped for recreation or any other uses, although some residential development exists. The Narragansett Bay's historical and natural resources presently contribute significantly to satisfying some outdoor recreation demands, and to enhancing the Providence area's quality of life. The Rhode Island SCORP proposes an Islands National Park including Patience and part of Prudence Island, Dutch, Despair and Gooseberry Islands.

FISH AND WILDLIFE RESOURCES

Woonasquatucket Drainage Area - The Woonasquatucket River basin has a moderate network of streams and ponds, but due to a high population density, particularly in the lower portion of the basin, it has very

little outstanding fish and wildlife habitat. Because the current habitat is insufficient or of low quality, it cannot support existing or projected future demands for hunting and fishing. Large portions of the land which can support fish and wildlife are privately owned, which also severely limits fishing and hunting recreation throughout the basin.

The Moshassuck and Woonasquatucket Rivers support limited aquatic life. In general the streams, ponds and impoundments of the upper portion of the basin are best suited for warm water fish, including smallmouth and largemouth bass, chain pickerel, white perch, yellow perch and brown bullheads. Each main stem has one tributary stocked with trout.

Vegetation along the upper reaches of the Moshassuck River is primarily mixed hardwoods, hardwood shrubs, and herbaceous plants and grasses along the riverbanks. The upper Moshassuck River contains many warm water species of game and nongame fish. The cooler portions of the river contain some hatchery stocked trout. The lower portion of the basin is highly urbanized with roads, parking lots and buildings lining the riverbanks and only sparse patches of weeds and shrubs. This segment of the river contains industrial waste and visible sewage. Pollution is severe enough so that several portions of the river are unable to support fish life.

Vegetation in the upper portion of the West River basin is primarily hardwood trees and shrubs. Fishing on Wenscott Reservoir is good, primarily for bluegills, sunfish and largemouth bass. Privately owned land surrounds much of the waterway, significantly limiting its recreational potential. Farther downstream in North Providence and Providence the riverbanks are lined with occasional clusters of parking lots, buildings and streets which are filled in with shrubs, plants and grasses. This lower portion of the West River is not fished althouth nongame fish can be found. Portions of the lower section of the West River are sluggish and contain industrial and human waste, although for the most part, pollution does not present a problem.

Vegetation in the Woonasquatucket River area is predominantly mixed hardwoods, conifers and shrubs, with arrowroot and grasses along the upstream banks. Water chemistry in the Stillwater Reservoir and Pond is very good and supports a high fish population including sunfish, bluegills, largemouth bass and pickerel. Farther downstream in Johnston, North Providence and Providence, industrial pollution becomes evident in the forms of oils and soapy film. In places where the river is not lined with parking lots and industry, a few hardwoods, a great deal of shrubs and grasses, and some submergent grasses can be found. In the Johnston - North Providence segment of the river fishing pressure is very high with good success, although poor accessibility is a limiting factor. The lower section of the Woonasquatucket River is extremely polluted and unable to support fish life.

Forests in the Woonasquatucket River basin are primarily of the elm-ash-red maple and oak-hickory types. Wetlands are bordered by forests and provide good wildlife habitat. A sigificant portion of the forested land is composed of relatively even aged, fully-closed stands of trees which do not support high wildlife populations. Migrant and resident species of waterfowl use inland wetlands for resting and feeding places.

Pawcatuck Drainage Area - A substantial portion of the Pawcatuck River planning area is rural with 91 percent of the basin consisting of forest, wetlands, open water or agricultural lands. The US Fish and Wildlife Service has estimated that 75 percent of the forest land is fair wildlife habitat, although the State rates this wildlife habitat somewhat higher. Due to an abundance of natural water areas and wetlands there are significant numbers of fur-bearing animals and forest game species.

The Pawcatuck River basin has an extensive network of streams and ponds. The Wood River is considered the best trout stream in the State of Rhode Island. Worden Pond provides the best northern pike fishing within the Pawcatuck and Narragansett Bay study area.

About 22,400 acres of public land and 66,000 acres of private land are open to hunting. This total should meet future demands for hunting, however, due to the close proximity of the Pawcatuck River basin to the Providence metropolitan area, much of the largely unmet hunting demands of that city will be diverted to this area. While all public and quasi-public lands receive heavy hunting pressure private lands accommodate the majority of hunters.

The Rhode Island Department of Natural Resources has acquired a number of pond and river access points, but additional access points are desirable for meeting future demands, even though there are enough available freshwater fishing areas to meet current demands.

Narragansett Bay Drainage Area - The Narragansett Bay local drainage area has an extensive network of streams and ponds. However, most of the streams are relatively small and contribute very little in the way of freshwater fishing. The open bay waters, salt ponds, freshwater areas and wetlands do, however, provide habitat for significant numbers of waterfowl. The basin's ponds and streams are relatively free of pollution and provide moderate fishing opportunities.

Harvestable cold water fish species include brook, brown and rainbow trout. The principal warm water fish species include largemouth bass, smallmouth bass, chain pickerel, yellow perch, white perch, brown bullheads and various sunfish. The Massachusetts Division of Fisheries and Wildlife and the Rhode Island Division of Fish and Wildlife have extensive trout stocking programs to meet the demand for stream fishing. The Palmer River in Massachusetts and the Hunt River in Rhode Island are considered to be the best trout streams in the area. As in the Pawcatuck River basin, private lands still sustain the bulk of hunting pressure,

although utilization of public and quasi-public lands is extensive. In both the Woonasquatucket and Pawcatuck, as well as the Narragansett Bay drainage areas, urban developments, intensive recreational lands, mining and waste disposal sites are low in wildlife numbers, but outlying residential areas usually are well populated by songbirds and some game birds and animals.

Principal wildlife species found within the three studied drainage areas include white-tailed deer, snowshoe hare, cottontail rabbit, red and gray squirrel, opossum, raccoon, pheasant, quail, ruffed grouse, woodcock, mourning dove, bobwhite, ducks, geese, herons, shorebirds, red and gray fox, woodchuck, mink, muskrat, weasel, skunk, porcupine, beaver, otter and bobcat.

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ECONOMICS

APPENDIX 6
ECONOMICS

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CHAPTER 6
ECONOMICS

WEST-MOSHASSUCK RIVER BASIN

Costs and Annual Charges

A preliminary cost estimate was prepared for the West-Moshassuck major channel improvement plan. The West-Moshassuck estimates are shown in Appendix 4 as Tables 4-1 and 4-2. The project first cost for the channel improvements is $24,309,000. Interest at a rate of 7-5/8% over three years of construction amounts to $2,780,000, which brings the total investment up to $27,890,000. Annual charges are $2,067,400, based on 7-5/8% interest and a 100-year project life.

Benefits

Flood control benefits are defined as flood damages prevented and are based on estimates of potential damages in the flood plain. Flood damage surveys were conducted which provide monetary estimates of both physical and non-physical losses, by property type, related to various stages or elevations of flooding. The result of these surveys are stage-damage relationships referenced to specific flooding elevations experienced in a flood of record. The determination of annual damages requires the correlation of hydrological stage-frequency data for each damage reach and stage damage data to produce damage-frequency relationships. Plates 6-1 and 6-2 show these relationships.

Benefit/Cost Ratio

The benefits attributable to the major channel improvement plan on the West River are approximately $924,000, and on the Moshassuck River are approximately $80,000, resulting in total benefits of $1,004,500. The annual cost of this project is approximately $2,067,400, and the benefit to cost ratio (BCR) is 0.49 to 1.

WOONASQUATUCKET RIVER

Flood Damage Survey

Estimates of potential flood damage along the Woonasquatucket River in Providence were determined by a damage survey conducted during June 1977. New England Division analysts collected data on the extent and nature of the areas flooded, the depth of flooding and the amount of damage experienced during the flood of 1968 at each damage site. Recurring losses were then estimated for the various stages above and below the March 1968 flood level to develop stage - loss relationships. Much of the information was obtained through interviews with knowledgable

city officials and property owners and managers. In some cases, estimates were modified by the analysts. Sampling methods were used whenever similar types of property were subject to approximately the same depth of flooding.

Recurring Losses

Recurring losses were summarized by stage at each damage site. For the portion of the Woonasquatucket River surveyed, it was estimated that recurring losses for a flood at the level of the March 1968 flood would be approximately $2,500,000. Of these losses the largest share, 76.9%, would be in damages to industrial property. Of the remaining losses, 12.5% would be in damages to commercial property, 5.6% in damages to homes, and the rest in damages to utilities, railroads, highways, bridges, and public properties.

Recurring losses at the +5 stage, five feet above the March 1968 flood level, would be approximately $44,000,000. The composition of losses at this level is slightly different with 71.1% of the losses in damages to industrial property and 19.6% in damages to commercial property. Other property losses would be in about the same proportion as at the 0 stage flood levels. Recurring losses are displayed in Table 6-1.

Average Annual Losses

In order to determine average annual losses a "stage-damage curve" was plotted from the summary of recurring losses. Hydrologic stage-frequency data was combined with the respective stage-damage data to extract the relationship between dollar damage at a given stage and the frequency of an event. The average annual losses were read off of this "damage-frequency curve."

The damage survey estimated losses to the +5 level, that is, five feet above the March 1968 flood level. This level of flooding has a frequency of occurrence of about once in every 150 years. It was felt that it would be unnecessary and misleading to extrapolate losses any further for use in this analysis. The different in possible losses below the 300 year flood level was estimated to be small, about $55,000. Total average annual losses were therefore estimated to be about $839,000 without extrapolating losses beyond the estimates made by the surveyors.

Average Annual Benefits

Average annual flood protection benefits are derived by determining the difference between the average annual losses under present conditions and the average annual losses remaining after construction of the proposed project.

There were two projects under consideration. The major difference between them is that one would involve a slightly wider channel than the

TABLE 6-1
RECURRING LOSSES (1977 PRICE LEVEL)

	0 Stage (March 1968 Flood Level)		+5 Stage (Five Feet Above 1968 Flood Level)	
Property Type	Dollars in Thousands	Percent of Total Losses	Dollars in Thousands	Percent of Total Losses
Residential	142.0	5.6	2,378.8	5.4
Commerical	315.0	12.0	8,647.5	19.6
Industrial	1,934.6	76.9	31,011.3	70.1
Public	24.1	1.0	42.1	.1
Utilities, Rail-Roads, Highways, and Bridges	101.4	4.0	2,138.3	4.8
TOTAL	2,517.1	100.0	44,218.0	100.0

other. The larger channel would provide virtually complete protection to the 300-year flood level. The average annual flood protection benefits accruing to this project would be approixmately $679,000. The smaller channel would provide the same quality of protection to the 100-year level. The average annual flood protection benefits accruing to this project would be about $415,000.

Future Benefits

The purpose here is to determine the extent of possible future benefits due to growth and to evalute the practicality of computing such benefits in each of three benefit categories. These benfits categories are inundation reduction, intensification, and location. They are differentiated as follows:

1. The future inundation reduction benefit is the value of reducing flood losses to activities which will use the flood plain without a plan. The benefit consists of the reduction of the amount of future damages plus related costs such as floodproofing. Future damages are dicounted to the base year of the project.

2. The intensification benefit accrues to commercial, industrial and agricultural sections. The benefit is the value of a plan to activities, which, with protection, are enabled to utilized their land more intensively.

3. The location benefit is the value of making flood plain land available for new uses by reducing flood hazards to activities that would use the flood plain only with protection.

Field work was done to determine which future benefit categories have applicability in the Woonasquatucket flood plain. The following results in each of the three benefit catagories were obtained.

1. Future Inundation Reduction Due to Growth. Growth in residential land use is expected to be outside of Providence. This is the case because the residential area in the flood plain in Providence is well-developed. Existing recurring residential losses amount to 5.6% of all damages. Some urban inundation reduction benefits due to affluence growth are obtainable for future losses.

In the commerical and industrial sectors, little growth is possible. Current land use is not susceptible to substantial changes in the flood plain. Future damages to activities which would locate in the flood plain without a project are principally those that would replace vacated structures. Any replacements are assumed to sustain similar losses to those of the present occupants.

2. Intensification. None of the manufacturers surveyed reported any underutilized space due to possible flooding. A survey of commerical

establishments gave substantially the same results. Space lost to wet cellars is neglibile as skids, pallets, and shelving are utilized to raise goods 4-6 inches off the floors.

3. Location. This benefit results from making the flood plain available to those who would locate there only with a plan. But flooding does not appear to be a factor in site preference. There are businesses locating in Providence in the flood plain. The flood potential is unknown to most concerned. The businesses currently locating in Providence are occupying existing structures.

Conclusions

Future benefits due to economic growth are limited by the lack of vacant and buildable land. The intensification benefit is insignificant in the Woonasquatucket River flood plain. Inundation reduction benefits due to affluence which would accrue to residences are equally small. Residential growth in the flood plain is not expected.

Economic activities do not consider possible flooding as a factor in locating in the flood plain of the Woonasquatucket River in Providence. There are businesses locating in vacated structures at the present time. These new occupants are economically comparable to the previous occupants.

Calculations of future benefits due to economic growth from the Woonasquatucket River is only warranted if they would result in a significant change in the benefit-cost ratio.

NARRAGANSETT BAY

Benefits and costs for the seven local protection projects considered in the Narragansett Bay local drainage area are shown on the following pages. Although some of the projects have benefit-to-cost ratios greater then unity, they lacked local support and were eliminated from further consideration. For descriptions of each project see Appendix 4.

TABLE 6-2

Benefits vs. Costs
Site 01

Item	Cost	Total Cost
Federal Investment		
Federal First Cost	$29,268,850	
Interest During Construction ($29,268,850 x .06375 x 1/2 x 2.5 years)	2,332,361	
Total Federal Investment	$31,601,211	
Federal Annual Charges		
Interest ($31,601,211 x .06375)	$ 2,014,577	
Amortization ($31,601,211 x .00013)	4,108	
Total Federal Annual Charges		$2,018,685
		$2,018,700 (Rounded)
Non-Federal Interest		
Contributed Funds	$12,343,882	
Lands, Easements and Rights-of-Way	882,925	
Total Non-Federal First Cost	$13,226,807	
Interest During Construction ($13,226,807 x .06375 x 1/2 x 2.5 years)	1,054,011	
Total Non-Federal Investment	$14,280,818	
Non-Federal Annual Charges		
Interest ($14,280,818 x .06375)	$ 910,402	
Amortization ($14,280,818 x .00013)	1,857	
Maintenance and Operation	293,094	
Total Non-Federal Annual Charges		$1,205,353
		$1,205,400 (Rounded)
Total Annual Charges		$3,224,100
Annual Benefits		
Flood Damage Prevention	$2,366,500	
Total Annual Benefits		$2,366,500

Benefit/Cost Ratio = 0.73 to 1.

TABLE 6-3

Benefits vs. Costs
Site 02 - Alternative "A"

Item	Cost	Total Cost
Federal Investment		
Federal First Cost	$19,467,589	
Interest During Construction		
($19,467,589 x .06375 x 1/2 x 2.5 years)	1,396,191	
Total Federal Investment	$20,863,780	
Federal Annual Charges		
Interest ($20,863,780 x .06375)	$ 1,330,066	
Amortization ($20,863,780 x .00013)	2,712	
Total Federal Annual Charges		$1,332,778
		$1,332,800 (Rounded)
Non-Federal Interest		
Contributed Funds	$ 8,185,926	
Lands, Easements and Rights-of-Way	545,728	
Total Non-Federal First Cost	$ 8,731,654	
Interest During Construction		
($8,731,654 x .06375 x 1/2 x 2.5 years)	626,223	
Total Non-Federal Investment	$ 9,357,877	
Non-Federal Annual Charges		
Interest ($9,357,877 x .06375)	$ 596,565	
Amortization ($9,357,877 x .00013)	1,217	
Maintenance and Operation	193,056	
Total Non-Federal Annual Charges		$ 790,838
		$ 790,800 (Rounded)
Total Annual Charges		$2,123,600
Annual Benefits		
Flood Damage Prevention	$7,457,700	
Total Annual Benefits		$7,457,700

Benefit/Cost Ratio = 3.51 to 1.

TABLE 6-4

Benefits vs. Costs
Site 03 - Alternative "A"

Item	Cost	T Cost
Federal Investment		
Federal First Cost	$13,492,387	
Interest During Construction		
($13,492,387 x .06375 x 1/2 x 2.5 years)	967,657	
Total Federal Investment	$14,460,044	
Federal Annual Charges		
Interest ($14,460,044 x .06375)	$ 921,828	
Amortization ($14,460,044 x .00013)	1,880	
Total Federal Annual Charges		$ 923,708
		$ 923,700 (Rounded)
Non-Federal Interest		
Contributed Funds	$ 5,685,680	
Lands, Easements and Rights-of-Way	379,045	
Total Non-Federal First Cost	$ 6,064,725	
Interest During Construction		
($6,064,725 x .06375 x 1/2 x 2.5 years)	434,954	
Total Non-Federal Investment	$ 6,499,679	
Non-Federal Annual Charges		
Interest ($6,499,679 x .06375)	$ 414,355	
Amortization ($6,499,679 x .00013)	845	
Maintenance and Operation	133,891	
Total Non-Federal Annual Charges		$ 549,091
		$ 549,100 (Rounded)
Total Annual Charges		$1,472,800
Annual Benefits		
Flood Damage Prevention	$ 704,000	
Total Annual Benefits		$ 704,000

Benefit/Cost Ratio = 0.48 to 1.

TABLE 6-5

Benefits vs. Costs
Site 02 - Alternative "B" and Site 03 - Alternative "B"

Item	Cost	Total Cost
Federal Investment		
Federal First Cost	$32,658,566	
Interest During Construction		
($32,658,566 x .06375 x 1/2 x 2.5 years)	2,602,479	
Total Federal Investment	$35,261,045	
Federal Annual Charges		
Interest ($35,261,045 x .06375)	$ 2,247,892	
Amortization ($35,261,045 x .00013)	4,584	
Total Federal Annual Charges		$2,252,476
		$2,252,500 (Rounded)
Non-Federal Interest		
Contributed Funds	$13,744,285	
Lands, Easements and Rights-of-Way	916,286	
Total Non-Federal First Cost	$14,660,571	
Interest During Construction		
($14,660,571 x .06375 x 1/2 x 2.5 years)	1,168,264	
Total Non-Federal Investment	$15,828,835	
Non-Federal Annual Charges		
Interest ($15,828,835 x .06375)	$ 1,009,008	
Amortization ($15,828,835 x .00013)	2,058	
Maintenance and Operation	326,362	
Total Non-Federal Annual Charges		$1,337,508
		$1,337,500 (Rounded)
Total Annual Charges		$3,590,000
Annual Benefits		
Flood Damage Prevention	$8,870,200	
Total Annual Benefits		$8,870,200

Benefit/Cost Ratio = 2.47 to 1.

TABLE 6-6

Benefits vs. Costs
Site 04

Item	Cost	Total Cost
Federal Investment		
Federal First Cost	$4,993,504	
Interest During Construction		
(Construction Time = 1.5 years)	0	
Total Federal Investment	$4,993,504	
Federal Annual Charges		
Interest ($4,993,504 x .06375)	$ 318,336	
Amortization ($4,993,504 x .00013)	649	
Total Federal Annual Charges		$ 318,985
		$ 319,000 (Rounded)
Non-Federal Interest		
Contributed Funds	$2,094,206	
Lands, Easements and Rights-of-Way	139,614	
Total Non-Federal First Cost	$2,223,820	
Interest During Construction		
(Construction Time = 1.5 years)	0	
Total Non-Federal Investment	$2,233,820	
Non-Federal Annual Charges		
Interest ($2,233,820 x .06375)	$ 142,406	
Amortization ($2,233,820 x .00013)	290	
Maintenance and Operation	46,168	
Total Non-Federal Annual Charges		$ 188,864
		$ 188,900 (Rounded)
Total Annual Charges		$ 507,900
Annual Benefits		
Flood Damage Prevention	$ 614,200	
Total Annual Benefits		$ 614,200

Benefit/Cost Ratio = 1.21 to 1.

TABLE 6-7

Benefits vs. Costs
Site 05

Item	Cost	Total Cost
Federal Investment		
Federal First Cost	$13,317,828	
Interest During Construction ($13,317,828 x .06375 x 1/2 x 2.5 years)	955,138	
Total Federal Investment	$14,272,966	
Federal Annual Charges		
Interest ($14,272,966 x .06375)	$ 909,902	
Amortization ($14,272,966 x .00013)	1,855	
Total Federal Annual Charges		$ 911,757
		$ 911,800 (Rounded)
Non-Federal Interest		
Contributed Funds	$ 5,602,896	
Lands, Easements and Rights-of-Way	373,526	
Total Non-Federal First Cost	$ 5,976,422	
Interest During Construction ($5,976,422 x .06375 x 1/2 x 2.25 years)	428,622	
Total Non-Federal Investment	$6,405,044	
Non-Federal Annual Charges		
Interest ($6,405,044 x .06375)	$ 408,322	
Amortization ($6,405,044 x .00013)	833	
Maintenance and Operation	132,091	
Total Non-Federal Annual Charges		$ 541,246
		$ 541,200 (Rounded)
Total Annual Charges		$1,453,000
Annual Benefits		
Flood Damage Prevention	$2,919,600	
Total Annual Benefits		$2,919,600

Benefit/Cost Ratio = 2.01 to 1.

TABLE 6-8

Benefits vs. Costs
Site 06

Item	Cost	Total Cost
Federal Investment		
Federal First Cost	$3,996,562	
Interest During Construction		
(Construction Time = 1.5 years)	0	
Total Federal Investment	$3,996,562	
Federal Annual Charges		
Interest ($3,996,562 x .06375)	$ 254,780	
Amortization ($3,996,562 x .00013)	520	
Total Federal Annual Charges		$ 255,300
		$ 255,300 (Rounded)
Non-Federal Interest		
Contributed Funds	$1,688,213	
Lands, Easements and Rights-of-Way	112,548	
Total Non-Federal First Cost	$1,800,761	
Interest During Construction		
(Construction Time = 1.5 years)	0	
Total Non-Federal Investment	$1,800,761	
Non-Federal Annual Charges		
Interest ($1,800,761 x .06375)	$ 114,799	
Amortization ($1,800,761 x .00013)	234	
Maintenance and Operation	37,033	
Total Non-Federal Annual Charges		$ 152,066
		$ 152,100 (Rounded)
Total Annual Charges		$ 407,400
Annual Benefits		
Flood Damage Prevention	$ 35,400	
Total Annual Benefits		$ 35,400

Benefit/Cost Ratio = 0.09 to 1.

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